CORPS OF ENGINEERS, U. S. ARMY

MISSISSIPPI RIVER COMMISSION

SOIL COMPACTION INVESTIGATION

REPORT NO. 1

COMPACTION STUDIES ON CLAYEY SANDS

TECHNICAL MEMORANDUM NO. 3-271

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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PREFACE

This report is the first of a series of reports to be published on various studies comprising a comprehensive soil compaction investigation. This investigation was authorized by the Office, Chief of Engineers, in May 1945 and performed by the Waterways Experiment Station in accordance with "Instructions and Outline for Soil Compaction Investigation" dated June 1945.

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PART I: INTRODUCTION

1. Presented herein are the results of a combined field and laboratory study on the compaction and stress-strain characteristics of a clayey sand. This study is a part of a comprehensive soil compaction investigation approved by the Office, Chief of Engineers, in May 1945, and performed by the Waterways Experiment Station in accordance with "Instructions and Outline for Soil Compaction Investigation" dated June 1945. This report is the first of a series of reports to be published on the various phases of the comprehensive investigation.

Purpose of the Study

2. The specific purposes of this phase of the investigation are stated in subparagraphs 2-b and 2-c of the "Instructions and Outline" as follows:

> "2-b. Determination of the stress-strain characteristics of soils compacted in the field by equipment now readily available for compaction purposes.
>
> "2-c. Determine the feasibility of the utilization of field compaction equipment of types now generally in use to obtain much greater compaction than is now generally required in fills."

Scope

3. The results of the investigation described in this report

provide a partial realization of the above-stated purposes. Objective "2-b" was not completely realized inasmuch as only CBR and unconfined compression tests were performed. Triaxial compression tests were scheduled but could not be performed because the samples could not be protected from high summer temperatures and cracked and dried out. Additional work is required to completely realize objective "2-c" because certain factors that affect compaction were held constant in this investigation and must be made variable in future work so that a complete determination of the effect of all factors influencing compaction will be accomplished. Briefly, the study was to consist of the following phases of work:

a. Preliminary survey work to locate a source of clayey sand material, and tests to determine the physical characteristics of various clayey sand mixes under dynamic and static compaction in the laboratory.

b. Construction of test fills of clayey sand using the following types of equipment for compaction: 34,500-lb D-8 tractor; a sheepsfoot roller loaded to produce 250, 450, and 750 psi; 19,500-lb wobble-wheel roller (1500 lb per wheel); 10,000-, 20,000-, and 40,000-lb rubber-tired wheel loads.

c. Field sampling and testing of test fills.

d. Laboratory tests on undisturbed samples procured from the test fills.

The variables present in any compaction work on a given soil with a given type of equipment are: (1) weight of roller, (2) contact pressure, (3) number of coverages, and (4) thickness of lifts. Items (1), (2), and, to a limited extent, (3) were investigated for compaction by sheepsfoot rollers. Item (1) was investigated for compaction by rubber-tired rollers. The other variables mentioned above but not investigated were outside the scope of the tests described in this report.

Definition of Pertinent Terms

4. For purposes of clarity, various terms used in this report are defined as follows:

Unit. A unit or test unit consists of an area of natural subgrade or a portion of a compacted fill which is compacted during the test at a given water content and under a given compactive effort with a given piece of compacting equipment.

Section. A section (usually several units) is an area of natural subgrade or a portion of a compacted fill constructed using one compactive effort at several water contents. A section, therefore, consists of a test area which is utilized in determining all or a part of a compaction curve for a given number of passes of a given piece of compacting equipment.

Compactive effort. This term can apply to either field or laboratory compaction. In the case of laboratory compaction a compactive effort consists of the application of a given amount of energy per unit volume of compacted soil. The compactive effort can be varied in the laboratory by changing the weight of the compacting hammer, number of blows per layer, or number of layers of soil in the compaction cylinder. In the case of field compaction a compactive effort consists of compaction by a given piece of equipment passing a given number of times on a given thickness of lift.

Trip. A trip of the compacting equipment refers to the passage of the equipment from one end of the compacted section to the other in one direction only. The term "round trip" is used for designation of a trip from one end of the section to the other and back.

Coverage. One coverage consists of one application of either a wheel of a rubber-tired roller or a foot of a sheepsfoot roller over each point in the area being compacted.

Pass. For a rubber-tired roller, pass and coverage are synonymous. For a sheepsfoot roller, one pass consists of one movement of a sheepsfoot roller drum over the area being compacted. The sheepsfoot roller used in this investigation required about 18 passes to accomplish one coverage.

Sheepsfoot roller. A double-drum, oscillating sheepsfoot roller, Model AD-132, manufactured by the American Steel Works. By loading the drums with increasing amounts of Baroid, foot contact pressures of 250 and 450 psi were obtained with one row of feet in contact with the ground. Each drum is 60 in. in diameter and has eight 7-in.-long feet in a row. The area of each foot is 7 sq in.

Wobble-wheel roller. This term applies to a wobble-wheel roller loaded to 1495 lb per wheel on 13 wheels, or 19,440 lb gross weight. Tires were inflated to a pressure of approximately 40 psi. This roller is referred to hereafter as a 1500-lb wobble-wheel roller.

20,000-lb wheel load. This load was furnished by a Model Super C Tournapull of 12-cu-yd capacity loaded to a gross weight of 80,000 lb, or 20,000 lb per tire. Tires were inflated to a pressure of approximately 55 psi; contact pressure was approximately 65 psi; and contact area was approximately 308 sq in.

40,000-lb wheel load. This load was furnished by a Tournapull of 32-cu-yd capacity, loaded to a gross weight of 160,000 lb, or 40,000 lb per tire. Tires were inflated to a pressure of approximately 57 psi;

contact pressure was approximately 69 psi; and contact area under this load was 580 sq in.

California Bearing Ratio or CBR. A measure of shearing resistance of soils to penetration which is determined by comparing the bearing value obtained from an arbitrary penetration-type shear test with a standard bearing value obtained on crushed rock (average value of a large number of tests). The standard results are taken as 100 per cent and values obtained from other tests are expressed as percentages of the standard. CBR may be modified by the terms laboratory, field in-place, soaked or unsoaked, according to conditions under which the tests were made; or by the terms design or evaluation, according to the purpose for which the test results will be used.

Dynamic compaction. Compaction of soil by the impact of a free-falling weight or hammer.

Static compaction. Compaction of soil by gradually increasing the compacting pressure, applied by means of a piston covering the entire surface of the specimen, up to any given amount. In the Porter static compaction method this pressure is 2000 psi.

Standard AASHO compaction. In this report it is assumed that a soil material is compacted by standard AASHO effort so long as the effort or work expended per unit volume of compacted soil is the same as that specified by standard AASHO method T-99-38. In order to perform CBR tests on compacted material and to study the effect of mold size, the standard AASHO equipment and methods were varied. However, in all cases the effort expended per unit volume of compacted soil is the same.

Modified AASHO compaction. A modification by the Corps of

Engineers of the standard AASHO compaction method, consisting of dynamic compaction in a CBR mold (6-in. diam) using 55 blows of a 10-lb hammer falling 18 in. on each of five equal layers. In this report the size of mold was increased to study the effect of mold size, and the number of blows was increased accordingly. The work expended per unit volume of soil was the same in all size molds.

PART II: TEST FILLS

Preliminary Survey Work

5. Several possible sources of the clayey sand material in the immediate vicinity of Vicksburg were explored and samples of the material were tested in the laboratory for determination of compaction and CBR characteristics. It was found that none of these materials satisfied requirements of a low-swelling clayey sand of low to medium plasticity. A pit was finally located near Clinton, Mississippi, about 40 miles east of Vicksburg, which satisfied the specifications for the type material desired for test fills. The borings indicated that, in general, the pit had approximately 1 to 6 ft of clayey silt overburden, underlain by approximately 2 ft of clayey sand containing 65-80% sand, which, in turn, was underlain by a layer of clayey sand more than 20 ft in thickness containing approximately 80-90% sand. Trial mixes of the two clayey sands were investigated in the laboratory and it was found that a blend of approximately 20% of the material containing 65-80% sand and 80% of the material containing 80-90% sand would yield a satisfactory material for test purposes.

6. Classification data for this material are shown on fig. 1 from which it can be seen that the blended material has a uniform gradation in the fine and medium sand sizes and a plasticity index of approximately 2. Soil similar to this type of material is found in much of the southeastern United States and has been used to a considerable degree as a base course material in highway and airport construction. The material has also been used to a great extent as surfacing on secondary roads.

7. The results of dynamic and static laboratory compaction and CBR tests on the clayey sand in the unsoaked and soaked condition are shown on figs. 2-5. A series of unconfined compression tests on specimens compacted dynamically and tested in the unsoaked condition were also performed on this material, the results of which are shown on fig. 6. It can be noted by reference to fig. 2 that modified AASHO maximum dry density is approximately 122 lb per cu ft at an optimum water content of 10%, and that standard AASHO maximum dry density is approximately 116 lb per cu ft at an optimum water content of 11.5%. The corresponding CBR values for these two compactive efforts are 65 and 15, respectively, in the unsoaked condition (fig. 2). and 47 and 15, respectively, for the soaked condition (fig. 3).

8. According to Part XII, Chapter 2, of the Engineering Manual, this material if used as a base course would generally be required to be compacted to 95% of modified AASHO maximum density at modified AASHO optimum water content. For this condition, which is 116 lb per cu ft dry density at 10% water content, the unsoaked CBR is 27, whereas the soaked CBR is 22. It is interesting to note that under 2000-psi static compaction, which is the original Porter or California method of compaction, this material has an optimum water content of approximately 13% and a maximum dry density of 112 lb per cu ft. The unsoaked CBR for the 2000-psi static compaction is 17, whereas the soaked CBR is 19. The reason for the soaked CBR being higher than the unsoaked CBR is the manner in which the statically compacted specimens are prepared for test purposes. Initially the material is placed in the CBR mold and compacted by one application of the piston under 2000 psi. The top of the specimen is then

subjected to a CBR penetration test. A maximum dry density of 112 lb per cu ft, an optimum water content of 13%, and an unsoaked CBR of 17 resulted from this penetration procedure. After penetrating the top of the specimen, the top inch of the material is scarified and a base plate placed on top of the mold. The mold is inverted and the 2000-psi load reapplied on what was previously the bottom of the specimen as initially compacted. This additional compaction increased the average density of the mold up to about 114 lb per cu ft, while still at the same optimum water content of 13%. The material is then allowed to soak, at the end of which time a CBR penetration test is performed. This test resulted in a value of 19%. For convenience and ready comparison of densities, water content, and CBR values, these data are tabulated as follows:

Type of Compactive Effort	Maximum Dry Density Lb/Cu Ft	Opt. W.C. Per Cent	CBR in Per Cent		Unconfined Compressive Strength Lb per Sq In.
			Unsoaked	Soaked	Unsoaked
Modified AASHO	122	10	65	47	20
95% Modified AASHO	116	10	27	22	12
Standard AASHO	116.4	11.5	15	15	10
Porter static (2000 psi)	112	13	17	--	--
	114.5*	13	--	19	--
	111	13	--	--	3

*High density value due to recompaction as discussed in paragraph 8.

9. It can be noted by reference to the above tabulation that the CBR at 95% modified AASHO density is less than one-half of that obtained at modified AASHO density. Under standard AASHO density the CBR is only about one-fourth of that obtained under modified AASHO density. Also,

under modified AASHO the unconfined compressive strength is 20 psi in the unsoaked condition, 12 psi at 95% of modified AASHO density, and 10 psi under standard AASHO density. The unsoaked CBR value of 17 obtained on specimens compacted under 2000-psi static compaction is in the general range of that obtained under standard AASHO compactive effort, but the unconfined compressive strength of 3 psi is much lower than that obtained for standard AASHO effort.

Location and Preparation of Materials

Location of test site

10. Because of the proximity of the clayey sand pit to the Clinton, Mississippi, Sub-Office of the Waterways Experiment Station, it was decided to construct the test fills on a portion of this reservation.

Pit operations

11. A total of approximately 15,000 cu yd of clayey sand material was needed for the tests. After stripping, it was found that soil variations occurred rather frequently but that in general the soil consisted of the two types discussed in paragraph 5. Accordingly, the material was examined at the borrow pit by an inspector, who classified the material as one or the other of the two basic types of clayey sand. The soil was excavated by a dragline using a 1/2-cu-yd drag bucket and transported to the test site by from three to six trucks of 3-cu-yd capacity.

Stock piles

12. The two clayey sand materials were stock-piled in adjoining areas at the field site. The material was spread on each stock pile in

thin layers, approximately 3 in. thick, with four-directional blading to produce intimate mixing and to crush out lumps. The water content of the interior of both stock piles remained close to 10%. It was necessary to air-dry the materials to reduce the water content to approximately 7% so that the material would flow freely through the batching bins of the mixing plant. Spreading and windrowing accelerated the drying. This air-dried clayey sand was piled in the areas adjacent to the mixing plant. During the latter part of the construction period an aggregate drier was used to accelerate drying of the clayey sand for use in the dry units of sections 8 and 9.

Mixing plant

13. The mixing plant consisted of a two-compartment aggregate bin with a three-beam batching scale mounted above a pugmill driven by a Diesel engine. A spray bar was installed over the pugmill and connected to a water batching tank with manual controls and gage. Clayey sand was loaded into the bins by a dragline equipped with a 1/2-cu-yd clamshell bucket. The clayey sand batch was weighed out and dumped into the pugmill. Water was added during the first part of the mixing period while the next batch was being weighed. The size of the batch was established at 1250 lb dry weight, which was sufficiently below the pugmill capacity to allow operation at a uniform speed. Batch weights were computed on a dry basis so that the setting of the scales was changed only with changes in the stock-pile water contents and not with changes in the batch water content. The plant produced 50 to 55 batches an hour when the stock-pile materials were dry enough to flow freely. As the water content of the materials

increased from 6% to 8 or 9%, sticking and bridging acted to slow down the production.

Construction

Layout

14. The test sections as actually constructed are shown on the layout on fig. 7. It can be noted that similar sections were placed in the same test area. This permitted simultaneous construction of one section of each type without traffic congestion. The ramp and shoulder limits were placed to allow shoulder slopes of approximately 1 on 5 and ramp slope of 1 on 10. A 20-ft transition of clayey sand was placed between the ramps and the end units of the test section to receive the carry-over of pit materials and to permit the entry of compaction equipment into the first unit at proper speed. Allowance was made on the 20,000- and 40,000-lb wheel load sections for the large turnarounds required by the Tournapulls. The test section number together with the type and number of passes of compaction equipment used is summarized below.

Test Section			Compactive Effort in Construction	
Number	Width-Ft	Length-Ft	Equipment Used	No. of Passes
2	50	200	450-psi sheepsfoot	9
3	40	200	250-psi sheepsfoot	9
5*	30	200	D-8 tractor	3
6**	30	200	1500-lb wobble-wheel	6
8	30	200	20,000-lb wheel load	4
9	40	200	40,000-lb wheel load	4 on 1/2 section 8 on 1/2 section

* Section 5 constructed 2 ft high; all others 5 ft.
** Section 6 constructed in 3-in. lifts; all others constructed in 6-in. compacted lifts.

It was originally intended to construct a section with a 750-psi sheepsfoot roller and a section with an 8,000-lb wheel load. These sections were eliminated however in the latter part of the program for reasons that are discussed in paragraph 47.

Ground-water conditions

15. At the start of field construction in June 1945, the ground-water table at the test areas was from 3 to 4 ft below the surface. In October the depth to ground water was greater than 6 to 7 ft. This change may be accounted for by normal seasonal fluctuation.

Subgrade preparation

16. The site was first cleared of brush and a system of connecting surface drainage ditches was built. The subgrades of the test areas were stripped of root-bearing topsoil and were scarified with a 24-in. disk and a Killifer plow. The water content of the subgrade soil was generally above its standard AASHO optimum, and the areas were left to dry during the period of clayey sand borrowing. From time to time they were opened up, aerated, and resealed. It was finally necessary to remove 1100 cu yd of wet subgrade soil and to replace it with material at a lower water content. Compaction of the refill material was performed with a tractor and wobble-wheel roller and the compacted areas were bladed to finished grade with a motor patrol. This procedure resulted in a firm subgrade satisfactory for the compaction test fills. All of the test areas were finished with slopes adequate for the quick drainage of rainfall, using the natural ground surface to maximum advantage. Prior to placing the first lift of clayey sand the subgrade surface was wetted to

restore proper moisture conditions.

Operation of compaction equipment

17. Sheepsfoot rollers. One sheepsfoot roller, an American Steel Works Model AD-132, was used in order to obtain the unit foot pressures required in construction of the clayey sand sections. The operating speed for all compaction equipment was first established at 3 mph. It was desired to have the test sections compacted so as to cover a range of density from approximately 95% of standard AASHO maximum density to greater than 100% modified AASHO density, if possible. The number of passes to be made with the 250- and 450-psi weights of sheepsfoot roller was therefore selected by preliminary experimental tests with the 250-psi roller. It was desired to approximate 95% of standard compaction with this roller. A unit consisting of three 6-in. lifts was constructed using the clayey sand at approximately standard AASHO optimum water content and compacted in lanes using 6 to 18 passes. The densities produced in this unit were as follows:

Number of Passes	Dry Density Lb/Cu Ft	Water Content Per Cent
6	108.2	11.4
9	110.3	11.4
12	112.0	12.0
15	113.4	12.5
18	114.3	11.2

The standard AASHO optimum density of the clayey sand was approximately 116 lb per cu ft. The number of passes constituting the sheepsfoot roller efforts was established on the basis of these 250-psi data as nine, which gave approximately 95% of standard AASHO density or 110 lb per cu ft.

The nine passes were performed in two series of trips; in the first series the roller was offset one tractor tread width (22 in.) each trip. Thus, when the tractor progressed completely across the section, the area had received two coverages of the tractor and six passes of the roller; the second series, offset two tread widths (44 in.) each trip, produced the remaining three passes of the roller.

18. It has been stated previously that the nominal or "rated" pressure intensity of sheepsfoot rollers is customarily computed with one row of feet in contact with the ground. This condition seldom if ever exists during actual operation. When the feet penetrate the soil more feet come in contact with the ground and the contact pressure may be reduced. For example, if the feet of the roller used in these tests penetrate the ground to such an extent that the drum of the roller just touches the ground, then the extremities of 24 teeth are below the surface of the ground. A penetration of only 4 in. will place the extremities of 16 feet below the ground surface.

19. The distribution of the forces involved on the different rows of feet of the roller is not known but is probably quite complex. It is probable that the feet emerging from the soil carry no load whatever on the face of the foot, but may have a pressure on the shank of the foot due to a "kicking" action discussed in a later paragraph. The load carried by the feet as they penetrate the soil undoubtedly varies over wide limits. It is probable that, with the roller in normal operation, a portion of the force required to pull the roller acts principally on the feet that are forward of the center of the drum and in contact with the soil. This force, while dependent on the weight of the drum, is an

addition to the forces developed by the dead weight of the drum acting alone.

20. The greatest possible load that could be carried by the feet occurs, during normal rolling operations, when the soil is so compact that only one row of feet is in contact with the soil. The least possible axial load applied to a row of feet during normal rolling operations would result if the following assumptions are made: (1) the feet emerging from the soil carry no load; and (2) each foot below and forward of the center of the drum in contact with the soil carries an equal axial load. For the roller used, six rows of feet are in contact with the soil when the drum just touches the ground. Three rows of feet are emerging and are assumed to carry no load. Three rows of feet are thus carrying the load and the axial pressure is therefore one-third of the rated foot pressure.

21. Another factor to be considered that affects the performance of a sheepsfoot roller, as explained below, may be called the effective or pitch diameter. The effective diameter is determined by observing the number of revolutions of the roller required for the roller to traverse a given distance. It is probable that the effective diameter is not constant for a given roller but varies with the type of soil, water content, and depth of penetration of the feet.

22. The drum of the roller used in this study was 66 in. in length and 60 in. in diameter. The length of feet was 7 in., making the over-all diameter 74 in. There were 120 feet on the drum (30 rows at four feet per row), and the end area of a foot was 7 sq in. If the effective radius is taken as 37 in., one-half the over-all diameter, then the area of a cylinder with a 37-in. radius and a 66-in. length is about 15,300

sq in. The total foot area is 840 sq in. so that the foot area is about 5.5% of the total area and about 18 passes of the roller are required for one coverage.

23. It can be shown graphically, by construction of a cycloid, that the feet of a roller enter and emerge from the soil in an almost vertical position if the effective radius is taken as the distance from the center of the drum to the outer end of the foot. Further, the roller, in effect, pivots about the end of the foot directly beneath the center of the drum and there is no relative horizontal movement between the face of the foot and the ground. However, if the radius of the drum is taken as the effective diameter, then the feet make a greater angle with the vertical when they penetrate and emerge from the soil. Also, the pivot point is now not at the outer end of the foot but at the point where the foot joins the drum. The face of the foot now moves horizontally with respect to the ground; the movement is to the rear, resulting in a kicking or shovel action. It is reasonable to suppose that a greater force would be required to tow the roller in the latter case. The actual effective diameter probably lies between the two extreme values just pointed out.

24. It was stated in the preceding paragraph that the effective diameter determined the position of the foot with respect to the vertical as it entered and emerged from the soil. If the position from the vertical is appreciable, the side of the shank will contact the soil when entering or emerging. This fact further complicates the computation of actual foot pressures. If the side of the foot or the shank contacts the soil they will carry some part of the load and the pressure on the face of the foot (paragraph 18) will be further reduced.

25. Inasmuch as the feet always penetrate into the ground a certain distance it is obvious from the discussion presented in the preceding paragraphs that when a layer of soil is compacted the pressure intensity on the face of the foot is not equal to the nominal or rated pressure, nor has the layer received a complete coverage with the number of passes used in the test. The stress developed in the soil beneath a roller foot diminishes with depth below the face of the foot but, at the same time, the area stressed increases. Thus, at some depth the areas subjected to stress from adjacent feet on the roller begin to overlap and a complete coverage results. However, the pressure intensity on the plane of such a complete coverage is much less than the pressure at the face of the foot.

26. Pneumatic-tired rollers. It was desired that the equipment used for each wheel load should be capable of exerting approximately the same contact pressure on the fill being compacted and the range of densities desired was to be the same as that specified for the sheepsfoot rollers (paragraph 17). The number of coverages to be made with the pneumatic-tired rollers was therefore selected by constructing and testing an experimental unit similar to that constructed with the 250-psi sheepsfoot roller. The range of densities obtained in the clayey sand with a tire load of 8000 lb is shown below:

Number of Coverages	Dry Density Lb/Cu Ft	Water Content Per Cent
2	111.8	14.0
4	114.0	12.5
6	115.8	12.6
8	116.1	12.1

These data indicate that two coverages of this wheel load produced a

density slightly greater than 95% of standard AASHO optimum. However, in the interest of obtaining uniform compaction, the tire-load efforts were established at four coverages. Tire-load compaction was performed by moving the equipment over one tire-print width per trip, the outside wheel track thus meeting the inside wheel track.

27. Wobble-wheel roller. Compaction with the 1500-lb wobble-wheel roller load was performed using six coverages in accordance with the directive.

28. Tractor. Compaction with the 34,500-lb D-8 tractor was performed using three coverages, which was the number of tractor coverages made in pulling the sheepsfoot roller nine passes, as discussed in the latter part of paragraph 17.

Fill construction

29. General. The clayey sand sections were built in the following order: (1) section 6, 1500-lb wobble-wheel load; (2) section 3, 250-psi sheepsfoot; (3) section 5, 34,500-lb tractor; (4) section 2, 450-psi sheepsfoot; (5) section 9, 40,000-lb wheel load; and (6) section 8, 20,000-lb wheel load. Mixing and placing of the material were continuous during two 10-hr shifts, with two sections being worked simultaneously. Compaction was carried out during daylight hours. The five units of each section, planned to bracket the optimum water content of the clayey sand, were arranged with water content increasing from south to north, downslope. In the sections adjoining shoulders (sections 3, 5, 6 and 8) each unit was entered directly from the shoulder, so that a minimum amount of compaction would be caused by filling and spreading operations. For the same reason, the interior sections (sections 2 and 9) were reached by the

end ramps, and filling progressed from the center unit to the ends. Ramps and shoulders were brought up level with fills and were built by a scraper with subgrade soil from nearby shallow borrows. No surfacing was used on ramps and turnarounds.

30. Protective surface covering. Each section was protected from excessive evaporation and from rainfall by covering throughout the construction period. While allowance for evaporation was made in the mixing water, the length of exposure was variable and unpredictable. The covers used were 18 by 42 ft and 18 by 52 ft and were made of prefabricated bituminous surfacing (PBS) which was available in rolls 300 ft long and 3 ft wide.

31. Placement procedure. Operations were begun with water content determinations on the material ready for placement in the plant hoppers and computation of batch quantities. The subgrade of the unit to be built was uncovered and mixing and hauling started. The water content of the mix was checked by grab samples from the second load and from every eighth to ninth load thereafter. On the fill, each load was dumped in a pattern based on the quantity of clayey sand computed for the unit lift and the 2500-lb truck load. The material was spread and leveled by bulldozers as soon as placed. A light tractor bulldozer was used in sections 3 and 6; a D-7 tractor bulldozer was employed in the other sections. Bulldozers were used in preference to a motor patrol for this work, because of their better maneuverability and low contact pressure. As rapidly as the material was spread, the PBS covers were replaced, to remain until the entire section was ready for compaction.

32. Compaction. Immediately prior to compaction the entire section

was uncovered and plowed with one pass of a Killifer plow, one pass of a Seaman pulvimixer, and a second pass of the Killifer, as shown in photograph 1. The water content of the loose layer was checked in samples from the center of each quarter of each unit. In a few instances water content adjustment was made by leaving the unit in question exposed while recovering the rest, or by sprinkling with a tank truck and repeating the mixing and testing. The first pass of the compaction equipment followed the final pass of the Killifer. In a representative number of lifts, check water content determinations were made after rolling was completed. When compaction operations were completed the section was again covered and remained so until placement of the next lift began. After compaction of the last lift in each section, the surface was dressed with a blade when necessary and then covered with PBS mat. The compaction of each section is described below.

a. Section 6 (1500-lb wobble-wheel load pulled by rubber-tired tractor). This section was constructed in 3-in. compacted lifts with average water contents in the units, respectively, of 8, 10, 12.5, 14, and 15.5%. Because trucks and roller bogged down in the wet end of the section, the water contents were changed beginning with the third lift to 6, 8, 10, 12, and 14%. Compaction of the 14% material was difficult. The rubber-tired tractor and wobble-wheel roller were seldom able to cross this unit without being towed. The material was displaced considerably when being rolled, which resulted in a very rough surface condition which had to be graded after each third lift was compacted. A light tractor bulldozer or light motor patrol performed this work.

b. Section 3 (250-psi sheepsfoot roller pulled by a 34,500-lb D-8 tractor). This section was constructed in 6-in. compacted lifts with average water contents in the units, respectively, of 6, 8, 10, 12, and 14%. In the 12 and 14% materials the roller produced a large degree of springing, and in the 14% material the pickup of material was excessive. The roller appeared to walk out about 3 in. during compaction of the 10 and 12% materials.

c. Section 5 (34,500-lb D-8 tractor). Material in this section was placed in 6-in. lifts at water contents in the various units of 6, 8, 10, 12 and 14%. The D-8 tractor produced some rutting and shoving in the 14% material. Elsewhere the compacted surface was regular. Vibration in the fill due to the moving tractor was much more noticeable than in the fills compacted by the sheepsfoot rollers pulled with the same tractor.

d. Section 2 (450-psi sheepsfoot roller pulled by 34,500-lb D-8 tractor). Material in this section was compacted in 6-in. lifts at water contents in the various units of 6, 7.5, 9, 10.5, and 12%. In the 12% material the roller produced a large degree of springing in the fill and a heavy material pickup. Very little walk-out of the roller during compaction was observed. The appearance of the roller in the different units after the first and last (9th) pass is shown in photographs 2-11.

e. Section 9 (40,000-lb wheel load). Material in this section was compacted in 6-in. lifts at water contents in the various units of 6, 8, 10, 12 and 14%. Although the west half of this section was compacted under four coverages of the wheel load and the east half was compacted under eight coverages of the load, the behavior under load and appearance of the two halves were very similar. The progressive deflection of the fill under this wheel load as the water content increased is shown in photographs 12-16 for the first coverage and in photographs 17-21 for the last four coverages. In the 12 and 14% material, the deflections resemble flood waves with the fill in motion for several feet in every direction from the moving wheel. The heavy ruts shown in the 14% material (photographs 16 and 21) were developed progressively but with shifting and reshaping under each successive trip.

f. Section 8 (20,000-lb wheel load). This section was constructed in 6-in. lifts at water contents in the various units of 6, 8, 10, 12, and 14%. This wheel load produced deflections of somewhat less than 2 in. in the material at 12%, and between 2 and 3 in. in the 14% water content. In the latter, rutting took place and increased with the number of coverages and in rolling it was difficult to keep the compaction equipment in line.

PART III: FIELD SAMPLING AND TESTING

33. During construction, water content determinations were made on the material in each lift, and sufficient density tests made to obtain preliminary information on the trend of density in several lifts. Following construction, density and water content determinations were made at 6-in. intervals throughout the entire depth of fill and test pits staked in each unit. In each test pit, field in-place CBR tests were performed at three depths and undisturbed samples in quadruplicate were obtained in CBR molds and in cubic-foot boxes adjacent to the field in-place CBR tests. Test pit samples were not taken below a depth of 34 in., as density determinations showed that densities did not increase below a depth of about 12 to 18 in.

Procedure and Methods

34. Samples for the construction-lift water content and density tests were obtained in thin-walled steel cylinders 3-3/4 in. in diameter and 5 to 6 in. in length. The cylinders were fitted with a threaded driving cap, an extension pipe 1-1/2 in. in diameter, and a pipe cap, and were driven with 12- or 14-lb sledge hammers. Samples for the density tests made after construction at 6-in. intervals throughout the depth of the section were also obtained by this method.

35. The field in-place CBR tests were conducted in accordance with instructions in Appendix C, "California Bearing Ratio Test as Applied to the Design of Flexible Pavements for Airports," Waterways Experiment Station Technical Memorandum 213-1, dated 1 July 1945. The improved truck-mounted apparatus, with a surcharge weight of 30 lb on a

10-in.-diam plate, was used in all tests. CBR tests were made in opposite corners of the test pit at depths of 3, 12, and 17 in. in section 5 (tractor compaction), and at depths of 3, 12, and 24 in. in the other sections. The truck was backed over the pit on tracks of pierced plank landing mat which protected the pit edges and the sample locations from traffic disturbance. Samples for the density tests made in connection with the CBR tests were obtained in thin-walled steel cylinders, 3 in. in diameter and 3 to 3-1/2 in. in length. These cylinders were driven by the use of a light-weight drop-hammer arrangement. Preliminary tests showed that no appreciable differences in densities were obtained when samples of the clayey sand material were taken by a hammer-driven cylinder and a hydraulically-driven cylinder. As a result of some compaction due to driving, samples taken with a hammer-driven cylinder of a material in a relatively loose condition may have a slightly higher density than samples obtained with a hydraulically-driven cylinder or those taken in test pits as described in the following paragraphs. Because of the greater ease and rapidity in obtaining samples, the hammer driving was resorted to in one phase of the test procedure.

36. Undisturbed samples for laboratory tests were obtained in wooden boxes and cylindrical molds at the same depths that field in-place CBR tests were performed. The box samples were 9-in. cubes and were obtained by digging out around a soil pedestal, trimming the pedestal to an approximate 9-in. cube and encasing it in paraffin and a wooden box. The cylindrical samples were 6 in. in diameter and 6 in. long and were obtained in a similar manner, except that the soil pedestal was trimmed oversize and a 7-in.-diam cylinder with a 6-in.-diam cutting edge was

forced down on the pedestal, so that a true cylinder-shaped sample was obtained. The annular space between the sample and cylinder was filled with paraffin and the top of the sample covered with wax paper and sealed with paraffin. The pedestals were then cut free and the bases trimmed and sealed with wax paper and paraffin. Typical steps in the sampling operations are shown in photographs 22 and 23.

PART IV: LABORATORY TESTING OF UNDISTURBED SAMPLES

37. As previously mentioned, the undisturbed samples that were obtained in cylindrical molds from the various test units were taken in duplicate at each elevation where CBR field in-place tests were performed. Upon receipt in the laboratory, one of these samples was penetrated in the as-compacted condition, and the second sample was placed in the soaking tank for a period of four days. At the end of the soaking period the sample was subjected to a CBR penetration test. Density and water content determinations were performed on each sample received in the cylindrical molds.

38. The undisturbed samples secured in boxes from the different test units were used for obtaining specimens for unconfined compression tests, which were performed on the material in the as-compacted condition. An effort was made to perform unconfined compression tests on soaked specimens in order to obtain shear strength data on this type of material when saturated. At first, however, it was not possible to use soaked specimens for these compression tests due to the fact that the specimens fell apart when the paper towel with which they were protected during soaking was removed. At a later date a different procedure was used and unconfined compression tests on soaked specimens were successfully accomplished. The small unconfined compression testing device and sampling apparatus developed by Dr. M. Juul Hvorslev were used for the performance of these tests. The samples were prepared by letting an entire box sample soak and then obtaining test specimens from the box by means of the thin-wall Hvorslev sampler.

PART V: RESULTS OF FIELD AND LABORATORY TESTS

Method of Presentation of Test Data

39. All test points from field determinations were plotted and a smooth curve drawn through the points. In all water content-density plots the curve was quite well defined. Points on the dry side of the optimum water content were sometimes as much as 3-4 lb per cu ft above and below the average curve for any given water content, but the variations were much less on the wet side of optimum. Variations of this magnitude occurred in spite of the carefully controlled placement procedures and are to be expected in field-compacted soils; however, good average values were obtained by making a sufficient number of determinations. Deviations from the average curve were somewhat greater in the case of CBR data, but the data shown are believed to represent the CBR of the soil as accurately as may practicably be obtained by means of a test of this nature.

Construction-Lift Moisture-Density Data

40. As previously indicated, density and water content determinations were made on construction lifts in the test sections as they were constructed. The results of these tests on five of the test sections are shown in figs. 8-12 and are typical of the data obtained. These data are shown in the form of moisture-density curves for different lifts in a given section. As indicated, the curves shown for a given piece of equipment were obtained from tests on samples obtained at the same time

after the construction of a particular lift. For instance, on fig. 9 the typical moisture-density data shown for lifts 3, 4 and 5 were developed from test data obtained on samples taken from each of these lifts immediately after construction of lift 6. In general, the moisture-density curves for the lifts close to the surface of the fill are more rounded in the vicinity of optimum water content than those at two to three lifts below the surface of the fill. It can also be noted that there is a tendency for the density at optimum water content to increase slightly with increase in depth down to about 12 to 18 in. At the 18-in. depth the tractor, 250-psi sheepsfoot roller, and 450-psi sheepsfoot roller sections all have the same maximum density of about 114 to 115 lb per cu ft at optimum water content. This is equivalent to approximately 94% of modified AASHO maximum density. For these same pieces of equipment at the 18-in. depth the optimum water contents are approximately 13.5, 13 and 11.5% for the tractor and the 250- and 450-psi sheepsfoot rollers, respectively.

41. In the case of pneumatic-tired equipment, reference to figs. 11 and 12 indicates that the observations regarding shape of compaction curves and increase in density with increase in depth just pointed out for the tractor and sheepsfoot rollers appear to hold equally as well for rubber-tired equipment. In comparing densities for the wobble-wheel roller at 3-, 6- and 9-in. depths with densities for the 40,000-lb wheel load, it can be noted that the maximum dry density for the wobble-wheel roller section (built in 3-in. lifts) and for the 40,000-lb section (built in 6-in. lifts) is approximately 116 lb per cu ft (95% modified AASHO density) at a constant optimum water content of approximately 12%.

Thus, it appears that pneumatic-tired equipment gives slightly greater densities for the clayey sand material than the tractor or sheepsfoot rollers, and it also appears that the equal densities obtained under pneumatic-tired equipment were obtained at the same optimum water content, whereas equal densities obtained under the tractor and sheepsfoot rollers were obtained at varying optimum water contents.

42. It can be noted by reference to figs. 8-12 that, for all practical purposes, the maximum densities obtained with the different types of equipment did not show any marked changes beyond a depth of about 12 to 18 in. On this basis it was decided that it would not be necessary to perform field in-place tests or to take undisturbed samples at depths greater than 24 to 34 in. Actually, when field sampling and testing were performed the maximum depth for field CBR tests was approximately 24 in., but density samples taken in connection with these CBR tests and undisturbed samples taken in cylinders and wooden boxes came from depths of 24 to 34 in. because of the length of the samples.

Field In-Place, CBR, Moisture, and Density Test Data

43. The results of field in-place CBR tests and corresponding water content and density determinations made on samples taken in volumetric cylinders immediately adjacent to the point where the in-place CBR test was performed are shown on figs. 13-19. The curves shown on these figures illustrate the variation of field in-place CBR and density with water content for three different depths. Moisture-density data substantiate construction-lift data previously discussed, with the possible exception that the optimum water content for the 450-psi sheepsfoot

roller section is approximately 12.5% instead of 11.5% and is therefore more nearly equal to the 250-psi sheepsfoot roller and tractor optimums than the differences indicated by construction-lift data. Although no 20,000-lb wheel load, construction-lift data were previously shown, the field in-place data for this wheel load shown on fig. 17 are in agreement with the wobble-wheel and 40,000-lb wheel load data.

44. The field in-place CBR data shown on figs. 13-19 are tabulated below:

	CBR at 12-In. Depth			CBR at 24-In. Depth		
Equipment	Maximum	Minimum	At Opt. W.C.	Maximum	Minimum	At Opt. W.C.
Tractor	13	3	6	14	3	4*
250-psi sheepsfoot	19	2	8	15	1	12
450-psi sheepsfoot	20	4	9	19	9	14
1500-lb wobble-wheel	18	6	6	18	1	8
20,000-lb wheel load	18	2	8	19	2	9
40,000-lb wheel load (4 coverages)	22	2	6	22	2	6
40,000-lb wheel load (8 coverages)	28	8	8	23	2	5

* 17-in. depth

It may be seen from the above tabulation that for the tractor and sheepsfoot compaction there is an apparent increase in both the maximum CBR and the CBR at optimum water content with increase in weight of compacting equipment. The data for the rubber-tired rollers do not reflect any positive effect of increased compactive effort for the CBR at optimum water content but do show a tendency for the maximum CBR to increase with increase in compactive effort.

CBR, Moisture, and Density Data from Undisturbed Samples Taken in Cylinders

45. The results of CBR tests made on unsoaked and soaked samples

taken in CBR molds from the various units are shown on figs. 20-26. . The moisture-density curves shown on these figures were obtained from water content and density determinations made on the sample received in each cylinder. It can be noted that these curves are not in exact agreement with similar curves shown on figs. 13-19. This difference is probably due in part to the slight variations in density and water contents existing in the fill. Data for curves on figs. 13-19 are from volumetric samples taken immediately adjacent to field CBR tests, while data on figs. 20-26 are from undisturbed samples taken at another location in the test pit. With the exception of the tractor section, the data for each type of compaction equipment were obtained on samples taken at three depths; samples in the tractor section were taken at only two depths.

46. The maximum density obtained in the cylinders from the tractor-compacted sections was about 112 lb per cu ft, whereas the maximum density of the cylinder samples from the 250- and 450-psi sheepsfoot roller sections was about 115 to 116 lb per cu ft, although the optimum water content as determined by data from the cylinder samples was constant at 12% for all three pieces of equipment. In the case of the pneumatic-tired equipment it appears that the wobble-wheel roller developed an average maximum dry density of 116 lb per cu ft at an optimum water content of about 12%, whereas the 20,000- and 40,000-lb wheel loads had equal maximum densities of approximately 117 lb per cu ft at a slightly lower optimum water content of approximately 11.5%.

47. As previously mentioned, it was intended originally to construct test sections with a 750-psi sheepsfoot roller and an 8000-lb rubber-tired wheel load. However, it was decided to abandon the 750-psi sheepsfoot

roller section, since examination of the field data revealed that the 250- and 450-psi sheepsfoot roller sections did not show any significant differences in maximum density and optimum water content.

48. Much the same reasoning was followed in eliminating the section to be constructed using the 8000-lb rubber-tired wheel load. The first section built with pneumatic-tired equipment was the wobble-wheel roller section. As pointed out before, the wobble-wheel roller produced maximum densities only slightly greater than those obtained with the sheepsfoot rollers. Because of the trend of the sheepsfoot roller data and the fact that the 20,000-lb wheel load rubber-tired equipment was being used elsewhere, it was decided to construct the 40,000-lb wheel load section immediately after the construction of the wobble-wheel roller section. The 40,000-lb wheel load equipment produced densities practically equal to or only slightly greater than the wobble-wheel roller. In scheduling the remainder of the construction it was therefore decided to abandon the section to be constructed with the 8000-lb wheel load but to include the 20,000-lb wheel load in order to have a better spread of rubber-tired wheel loads and to obtain a check on the wobble-wheel and the 40,000-lb wheel load data.

49. The range of unsoaked CBR values at optimum water contents obtained from tests made on cylinder samples showed no significant differences from values obtained by field in-place tests. This factor will be more fully discussed in paragraphs 57 to 63.

50. One significant trend seems to stand out for all types of equipment. This is for the case of the soaked CBR values, where it can be noted by reference to figs. 20-26 that the material on the dry side

of optimum water content swelled sufficiently on soaking to cause pronounced lowering of the CBR value over that obtained for the unsoaked condition at the same as-compacted density and water content. It is also important to note that for any given difference in water content from optimum, the soaked dry-side CBR and the soaked wet-side CBR were approximately equal, and that the maximum soaked CBR occurs at optimum water content. Also, the soaked and unsoaked CBR values at optimum water content are approximately equal.

51. The variations in CBR and density with water content for material compacted in the laboratory and in the field are summarized on fig. 27 for one depth at which samples were taken in the field. All the data obtained from field in-place tests and from soaked and unsoaked CBR tests on undisturbed samples from the 12-in. depth for all types of compaction equipment used are shown on this figure. A review of previous figures shows no significant difference in density and CBR values for samples taken at various depths. Therefore, for purposes of comparison, the 12-in. depth was taken as being representative of all depths.

52. The curves shown on fig. 27 are the same curves shown on figs. 13-26 for the 12-in. depth. Also shown on this figure are the results of standard and modified AASHO laboratory compaction tests and corresponding CBR-water content curves for material in the unsoaked condition, together with the Porter 2000-psi static compaction data and CBR curves in the unsoaked condition.

53. It appears from the data shown on fig. 27 that the compaction characteristics of the tractor, sheepsfoot roller, wobble-wheel roller and heavy rubber-tired rollers are very similar to those obtained by the

dynamic laboratory method of compaction. In general, the maximum dry densities obtained in the field are equal to or slightly less than those obtained by standard AASHO compaction and 6 to 10 lb less than obtained by modified AASHO compaction. As previously shown by the construction-lift, field in-place, and cylinder data in fig. 27, approximately 94 to 97% of modified AASHO compaction was obtained by the field equipment for the number of passes used. The range of CBR values of field-compacted material was also more nearly equal to those obtained from specimens compacted by standard AASHO effort than by modified AASHO or Porter 2000-psi compaction.

54. The optimum water content, maximum dry density, and CBR for dynamic and static laboratory compaction, and all of the data from field test fills compacted with various types of equipment, are tabulated and shown in table 1. This table was prepared by first listing the optimum water content and density developed by standard and modified AASHO laboratory compactive effort and each piece of field compaction equipment. Two values are shown for the field data because water content and density values corresponding to field in-place CBR values were obtained from density tests made adjacent to the penetration test and similar data for the undisturbed cylinder samples were determined directly from the sample tested. The CBR values listed under the heading of "Field Compaction" are actual field test values. The CBR values shown for laboratory dynamic and static compaction in a 6-in. mold were obtained from figs. 2-5 for the water content and density values listed in the figure. Data for the 7.4-in.-and 12-in.-diam molds were taken from a letter report dated 1 October 1945 to Office, Chief of Engineers, subject "Preliminary Results

of Tests to Study the Effect of Mold Size on CBR." This table permits a direct comparison of CBR values of material compacted in the laboratory and in the field at the same water contents and densities. It is important to note that at optimum water content the CBR values for soaked undisturbed samples are about equal to the unsoaked value except for the 250-psi sheepsfoot roller section.

55. As it has been general practice to specify that a certain degree of compaction be obtained at modified AASHO optimum water content, the densities and CBR values obtained in the field at this water content are given in table 2. For the clayey sand used in this investigation, the modified AASHO optimum water content is 10%. In the case of the data for the field-compacted specimens, the data shown in tables 1 and 2 are taken from figs. 13-26 for the 12-in. depth. These data show that none of the field equipment approached modified AASHO density at this water content for the number of passes of equipment used. It further shows that all field CBR values are more nearly equal to CBR values obtained on dynamically compacted laboratory specimens than on statically compacted specimens.

Results of Unconfined Compression Tests

56. The results of unconfined compression tests performed on 2- by 4-in. specimens cut from the undisturbed test pit samples obtained from various units are shown on figs. 28 and 29. These data are for the clayey sand in the unsoaked condition. Tests were performed on samples taken from three different depths in the test fills but there was no significant difference in the dry densities obtained at the various

depths. Therefore, all test points were plotted (water content vs dry density and compressive strength) disregarding depth. This resulted in a sufficient amount of reliable data to allow plotting of water content-density curves and to establish a trend of variation of unconfined compressive strength with water content. Points shown on figs. 28 and 29 are averages of several points, which were arrived at by using the same procedure as was used in plotting the water content-density curves and the variation of CBR with water content curves for the field-compacted fills. Results of these tests are summarized on fig. 30. A comparison of unconfined compressive strength of laboratory-compacted specimens with field-compacted specimens is shown in table 3. It appears from the data shown in this table that the field-compacted material has strength characteristics very similar to those of dynamically compacted laboratory specimens. This is also true in regard to the strain characteristics of the material, as no appreciable differences in the stress-strain curves were obtained from material compacted by dynamic effort in the laboratory or by sheepsfoot rollers or rubber-tired rollers in the field.

PART VI: DISCUSSION OF CBR TESTS

57. In the letter report to the Chief of Engineers, dated 1 October 1945, subject "Preliminary Results of Tests to Study the Effect of Mold Size on CBR", it was shown that CBR values decreased with increasing mold size. Additional data obtained from the field tests reported herein permit further conclusions regarding the effect of mold size on CBR values and are discussed in the following paragraphs.

58. It is considered that variations in CBR values due to mold size may be due to at least two causes: (1) the confining effect of the mold during compaction of the specimen; and (2) the confining effect of the mold during the penetration of the specimen. CBR values of the clayey sand were obtained from three sources: namely,

- a. Specimens compacted in molds in the laboratory and penetrated in molds.
- b. Undisturbed field samples, compacted in the field by field equipment and penetrated in molds.
- c. Field in-place tests, compacted in the field and penetrated in the field.

Thus, if CBR values from a and b are equal to each other and are higher than c, it would appear that differences are due to the confining effect of the mold during the penetration of the piston. On the other hand, if b and c are equal to each other and are lower than a it would appear that differences are due to the confining effect of the mold during compaction.

59. Table 4 presents the ratio of CBR values for field in-place, mold, and laboratory tests. Data shown under "Optimum Water Content" were computed from values given in table 1, and under "10% Water Content" from table 2. Column (1) is the ratio of CBR values from laboratory

compacted and penetrated molds to values from field in-place tests. It is apparent that the laboratory values are higher than the field in-place values for all types of compaction equipment and that the values of the ratios fall naturally into two groups consisting of the tractor-sheepsfoot rollers and the pneumatic rollers. Similarly, it can be seen in column (2) that laboratory-compacted values are appreciably higher than field-mold values. It is not possible to get a ratio of field in-place values to mold values directly, as the densities are not equal (tables 1 and 2). However, an approximation can be obtained by simply dividing the ratios in column (2) by those in column (1), as shown in column (3). The values obtained are not absolutely correct, as the water contents are not constant, but are sufficiently accurate for purposes of comparison. A comparison of CBR curves on fig. 27 for field in-place and cylinder tests shows that the computed ratios are approximately correct. Summarizing, it appears that at the optimum water content for pneumatic rollers, unsoaked CBR values from laboratory tests are about 2.1 times as great as from field in-place tests and 2.9 times as great as from tests on undisturbed mold samples. Also, the field in-place values are about 1.4 times as great as mold values. The same trend is evident for the tractor-sheepsfoot data but the differences are not as great.

60. The fact that CBR values from tests on undisturbed molds are lower than values from field in-place tests cannot be definitely explained. The method of obtaining the undisturbed mold samples has been explained in paragraph 35 and illustrated by photographs 22 and 23. During sampling, all confining effects of the surrounding soil are removed and the sample is thus afforded an opportunity to expand or to rebound from the

constraining effect of the surrounding soil and to reach a state of equilibrium with no confinement. Therefore, it is probable that undisturbed samples when tested in CBR molds actually have less confinement than soil that is tested in place.

61. The data from soaked specimens in columns (4) and (8) show much the same trend as pointed out for the unsoaked data at optimum water content. The unsoaked data for 10% water content, which is dry of optimum, are rather erratic. Note, however, that column (7) agrees with column (3), in that field in-place CBR values are higher than values from undisturbed molds.

62. Referring to paragraph 58, it is believed that the effect of mold size on CBR values is due to a great extent to the confining effect of the mold during compaction, as condition a is definitely greater than conditions b and c. Positive conclusions cannot be made concerning the confining effect of the mold during penetration, due to the uncertainties of the confinement of undisturbed samples penetrated in molds.

63. The foregoing discussion is not intended to establish any fixed relationship between CBR values from field in-place tests and conventional laboratory values, as sufficient data are not available for this purpose. It is believed that sufficient data have been obtained to show, for this particular soil, that field in-place values and laboratory values cannot be used interchangeably, and that caution should be used with CBR values from in-place tests for every soil until some relationship has been definitely established. The results of unconfined compression tests show that the strengths of material compacted in the laboratory and in the field (table 3) are about equal. This fact tends to confirm the opinion

that the low field in-place CBR values are not a true measure of the strength of the soil relative to the strengths shown by laboratory compaction tests.

64. Another characteristic of this clayey sand worthy of note is that the soaked CBR value at low densities is practically independent of water content, as can be seen by the curves in the right hand plot of fig. 3. Table 5 shows the CBR value at 1% dry of optimum, at optimum, and 1% wet of optimum water content for all types of compacting equipment. Thus, changes in water content near optimum are not critical for this material, insofar as CBR values are concerned.

PART VII: SUMMARY AND CONCLUSIONS

65. Based on the data presented in this report, the following summary and conclusions appear to be warranted <u>for the clayey sand studied</u>:

a. Due to the highly plastic character of the material passing the 200-mesh screen (plasticity index = 45), the material exhibited compaction characteristics of a fine-grained material rather than a sand, as illustrated by the marked effect of moisture content.

b. The following maximum dry densities, expressed as a percentage of modified AASHO maximum density, were obtained:

Equipment	No. of Passes	Height of Lift - In.	Modified AASHO Density in %
34,000-lb tractor	3	6	91-92
250-psi sheepsfoot	9	6	94
450-psi sheepsfoot	9	6	93-95
15,000-lb wobble wheel	6	3	94-95
20,000-lb wheel load	4	6	95
40,000-lb wheel load	4	6	94-96
40,000-lb wheel load	8	6	95-97

It is noted that only a slight trend for increase in compaction occurred with the use of heavier equipment. It is further noted that the rubber-tired equipment gave slightly higher densities than did the tractor or sheepsfoot rollers for the number of passes used. The sheepsfoot roller did not walk out with increasing number of passes.

c. The optimum water contents, as developed by field equipment, were about equal to optimum water contents obtained by standard AASHO compaction as shown in the following tabulation:

Compactive Effort	Optimum Water Content
Standard AASHO	11.5
Tractor	12.0
250-psi sheepsfoot	12.0
450-psi sheepsfoot	12.2
15,000-lb wobble wheel	11.7
20,000-lb wheel load	11.5
40,000-lb wheel load	11.5

d. The stress-strain curves from CBR tests of field-compacted material were much more similar to curves of laboratory, dynamically compacted material than to statically compacted material.

e. In general, CBR values of field-compacted material did not agree with CBR values from laboratory-compacted material but varied in a systematic manner (see table 4).

f. The maximum soaked CBR for field-compacted material occurred at field optimum water content and the curve is symmetrical about this point for a range of about 2% in water content.

TABLES

Table 1

SUMMARY OF OPTIMUM WATER CONTENT, DENSITY, AND CBR FOR LABORATORY AND FIELD COMPACTION

Type of Compaction Equipment	Optimum Water Content Per Cent	Maximum Dry Density Lb/Cu Ft	Per Cent of Modified AASHO Density	California Bearing Ratio (CBR): Field Compaction: In Place	Field Compaction: Undisturbed Cylind. Samples: Unsoaked	Field Compaction: Undisturbed Cylind. Samples: Soaked	Dynamic Laboratory Compaction[a]: 6-in. Diameter Mold: Unsoaked	Dynamic Laboratory Compaction[a]: 6-in. Diameter Mold: Soaked	Dynamic Laboratory Compaction[a]: 7.4-in. Diameter Mold: Unsoaked	Dynamic Laboratory Compaction[a]: 12-in. Diameter Mold: Unsoaked	Static Laboratory Compaction[a]: 6-in. Diameter Mold: Unsoaked	Static Laboratory Compaction[a]: 6-in. Diameter Mold: Soaked
Modified AASHO	10.0	122.2	100	-	-	-	65	47	52	19	--	--
Standard AASHO	11.5	116.2	95	-	-	-	15	15	14	4	--	--
Static 2000 psi	13.0	114.3	94	-	-	-	--	--	--	--	17	19
34,500-lb tractor	13.5[b]	113.0[b]	92	6	-	-	9	7	3	3	17	18
(3 coverages)	12.0[c]	111.5[c]	91	-	7	5	11	9	6	3	20	8
250-psi sheepsfoot	12.7	115.3	94	8	-	-	11	11	8	-	25	21
(9 passes)	12.2	114.5	94	-	12	8	12	11	10	4	28	18
450-psi sheepsfoot	12.4	113.5	93	9	-	-	9	10	7	4	25	17
(9 passes)	12.3	115.5	95	-	7	8	12	10	8	4	29	20
1500-lb wobble-wheel	12.2	115.3	94	6	-	-	12	12	8	4	29	20
(6 coverages)	11.6	116.0	95	-	5	6	16	15	13	4	35	20
20,000-lb wheel load	12.2	116.0	95	8	-	-	15	14	7	4	31	21
(4 coverages)	11.3	116.5	95	-	8	9	20	18	14	5	38	20
40,000-lb wheel load	12.2	116.2	95	6	-	-	15	14	6	4	31	21
(4 coverages)	11.5	117.0	96	-	7	8	24	20	14	5	38	21
40,000-lb wheel load	12.0	116.0	95	8	-	-	15	15	8	4	32	21
(8 coverages)	11.3	118.0	97	-	13	13	32	23	15	5	40	23

Notes: a Laboratory CBR values corresponding to water contents and densities obtained in the field.
b Water contents and densities corresponding to in-place CBR determined by volumetric samples taken adjacent to test location (paragraph 35).
c Water contents and densities corresponding to CBR values of undisturbed cylinder samples on which CBR test was performed (paragraph 36).
Field data are from 12-in. depth.

Table 2

SUMMARY OF DENSITY AND CBR FOR LABORATORY AND FIELD COMPACTION AT MODIFIED AASHO OPTIMUM WATER CONTENT

	Field Compaction					Dynamic Laboratory Compaction CBR[b]				Static Lab. Compaction CBR[b]	
				CBR Undisturbed Cylind. Samples		6-in. Diameter Mold		7.4-in. Diameter Mold	12-in. Diameter Mold	6-in. Diameter Mold	
Type of Compaction Equipment	Dry Density at 10%[a] W.C.	Per Cent of Mod. AASHO Density	CBR In Place	Unsoaked	Soaked	Unsoaked	Soaked	Unsoaked	Unsoaked	Unsoaked	Soaked
34,500-lb tractor	107.5[c]	88	12	--	--	11	6	8	--	--	--
(3 coverages)	107.5[d]	88	--	9	6	11	6	8	--	--	--
250-psi sheepsfoot	109.5	90	19	--	--	12	9	11	3	17	8
(9 passes)	110.5	90	--	14	8	12	10	12	4	22	9
450-psi sheepsfoot	108.5	89	16	--	--	11	8	10	4	12	7
(9 passes)	112.5	92	16	14	8	14	13	16	4	37	12
1500-lb wobble-wheel	110.0	90	15	--	--	12	10	12	4	22	9
(6 coverages)	111.0	91	--	7	4	12	11	14	4	30	10
20,000-lb wheel load	110.0	90	13	--	--	12	10	12	4	22	9
(4 coverages)	113.2	93	--	10	6	15	14	18	4	39	13
40,000-lb wheel load	112.5	92	14	--	--	14	13	16	4	37	12
(4 coverages)	113.5	93	--	10	5	15	15	18	5	40	13
40,000-lb wheel load	111.0	91	16	--	--	12	11	14	4	30	10
(8 coverages)	115.2	94	--	15	10	22	19	22	6	45	16

Notes:
a Modified AASHO optimum water content.
b CBR values corresponding to densities obtained in the field at 10% W.C.
c Densities corresponding to in-place CBR determined by volumetric samples taken adjacent to test location (paragraph 35).
d Densities corresponding to CBR values of undisturbed samples determined from cylindrical sample on which CBR test was performed (paragraph 36).
Field data are from 12-in. depth.

Table 3

SUMMARY OF UNCONFINED COMPRESSION TEST DATA

Type of Compaction Equipment	Optimum W. C. %	Maximum Dry Density Lb/Cu Ft	Unconfined Compressive Strength Lb per Sq In. — Field Unsoaked	Field Soaked	Laboratory Unsoaked	Laboratory Soaked	Dry Density 10% W.C.	Unconf. Compress. Strength Lb per Sq In. at 10% W.C. - Unsoaked — Field	Laboratory
34,500-lb tractor (3 coverages)	12.5	111.0	6.1	---	5.0	---	108.2	7.0	5.0
250-psi sheepsfoot (9 passes)	12.5	113.0	7.4	---	6.0	---	110.5	9.2	6.5
450-psi sheepsfoot (9 passes)	11.5	115.0	7.2	6.0	8.5	6.0	112.9	8.8	8.2
1500-lb wobble-wheel (6 coverages)	12.0	117.5	9.3	---	10.6	---	112.0	10.1	7.5
20,000-lb wheel load (4 coverages)	11.7	118.2	9.2	7.5	11.5	7.5	115.0	10.0	---
40,000-lb wheel load (4 coverages)	12.4	116.9	9.0	---	9.5	---	113.3	11.0	8.8
40,000-lb wheel load (8 coverages)	11.0	117.0	11.0	---	11.0	---	115.0	12.8	10.3

NOTE: All unconfined compressive strength data for the field were obtained from specimens cut from 9-in. cubic box samples. All laboratory unconfined compressive strength data were obtained from dynamically-compacted specimens. All laboratory values correspond to densities obtained in the field at the field optimum water content, and to 10% water content (modified AASHO optimum) at the density obtained in the field.

Table 4

RATIO OF CBR VALUES FROM FIELD IN-PLACE, MOLD, AND LABORATORY TESTS

Compaction Equipment	At Field Optimum Water Content				At 10% Water Content[a]			
	Unsoaked			Soaked	Unsoaked			Soaked
	Lab.[b] / F.I.P. (1)	Lab. / Mold (2)	F.I.P. / Mold (3)	Lab. / Mold (4)	Lab. / F.I.P. (5)	Lab. / Mold (6)	F.I.P. / Mold (7)	Lab. / Mold (8)
34,500-lb tractor (3 coverages)	1.5	1.6	1.1	1.8	0.9	1.2	1.3	1.0
250-psi sheepsfoot (9 passes)	1.4	1.0	0.7	1.4	0.6	0.9	1.5	1.3
450-psi sheepsfoot (9 passes)	1.0	1.7	1.7	1.3	0.7	1.0	1.4	1.6
AVERAGE	1.3	1.4	1.1	1.5	0.7	1.0	1.4	1.3
1500-lb wobble wheel (6 coverages)	2.0	3.2	1.6	2.5	0.8	1.7	2.1	3.0
20,000-lb wheel load (4 coverages)	1.9	2.5	1.3	2.0	0.9	1.5	1.7	2.3
40,000-lb wheel load (4 coverages)	2.5	3.4	1.4	2.5	1.0	1.5	1.5	3.0
40,000-lb wheel load (8 coverages)	1.9	2.5	1.3	1.8	0.8	1.5	1.9	1.9
AVERAGE	2.1	2.9	1.4	2.2	0.9	1.6	1.8	2.5

Notes: [a] Modified AASHO optimum water content.

[b] Abbreviations in column headings have following meanings:

Lab. - Conventional laboratory CBR test in 6-in.-diam mold.

F.I.P. - Field in-place CBR test.

Mold - CBR tests on undisturbed samples taken in cylindrical molds.

Table 5

CBR VALUES AT WATER CONTENTS DRY AND WET OF OPTIMUM

Compaction Equipment	3-in. Depth			12-in. Depth			24-in. Depth		
	1% Dry	Optimum	1% Wet	1% Dry	Optimum	1% Wet	1% Dry	Optimum	1% Wet
250-psi sheepsfoot (9 passes)	7.0	8.0	8.0	8.5	8.0	7.0	8.0	10.0	10.0
450-psi sheepsfoot (9 passes)	---	---	---	9.0	8.0	---	5.0	4.0	3.0
1500-lb wobble-wheel (6 coverages)	4.0	4.0	4.0	5.0	6.0	7.0	3.5	4.0	5.0
20,000-lb wheel load (4 coverages)	5.5	6.0	5.0	6.5	9.0	6.5	8.0	10.0	8.0
40,000-lb wheel load (4 coverages)	6.0	6.0	---	6.0	8.0	6.0	7.0	7.0	6.0
40,000-lb wheel load (8 coverages)	10.0	10.0	6.0	11.0	13.0	9.0	12.0	11.0	7.0
34,500-lb tractor (3 coverages)	2.0	3.0	4.0	6.5	5.5	3.0	----	----	---

Note: CBR values obtained from tests made on undisturbed samples.

PHOTOGRAPHS

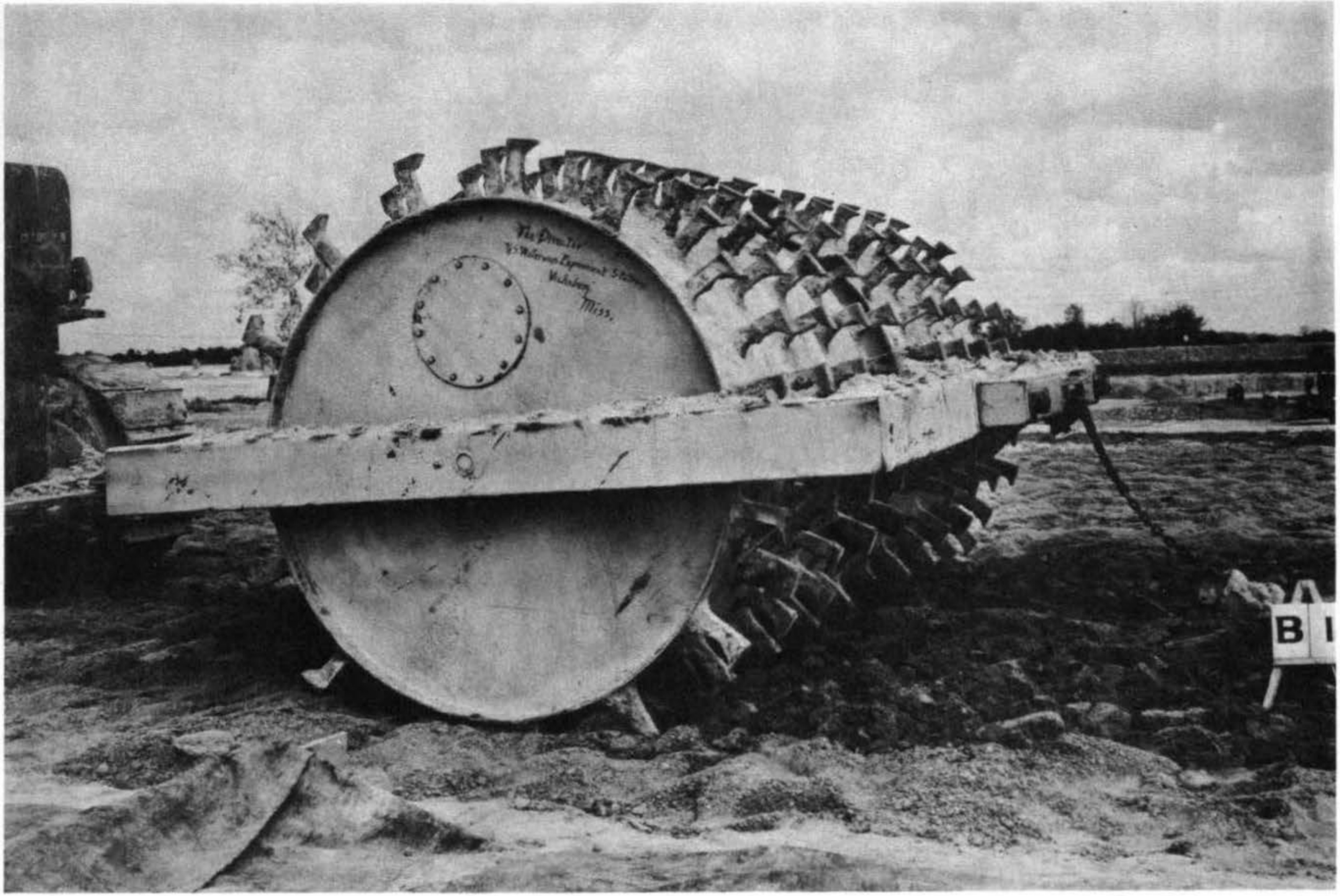
PHOTOGRAPH 1

Killifer plow and Seaman pulvimixer plowing material prior to compaction

PHOTOGRAPH 2

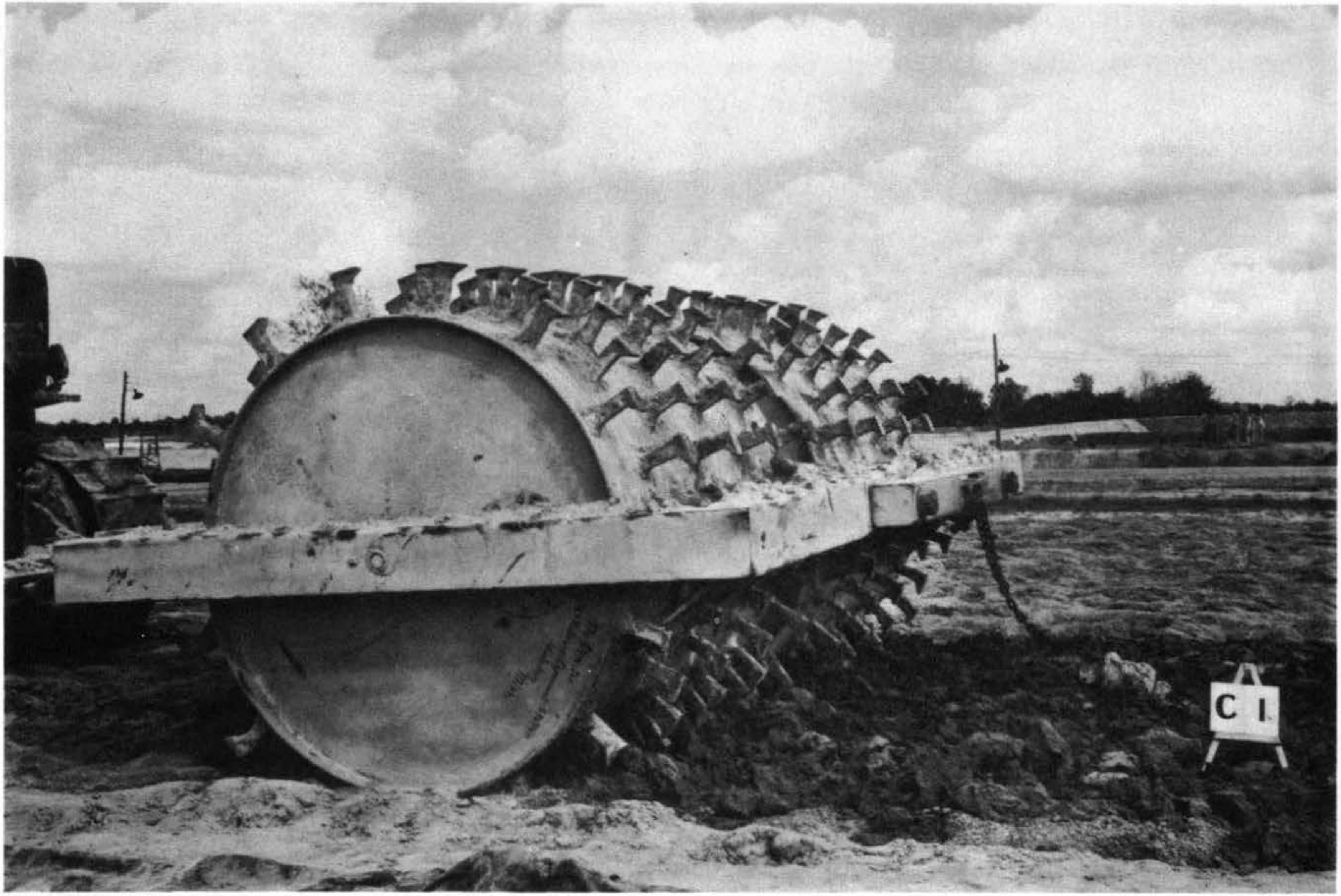
450-psi sheepsfoot roller, first pass, 6% water content

PHOTOGRAPH 3



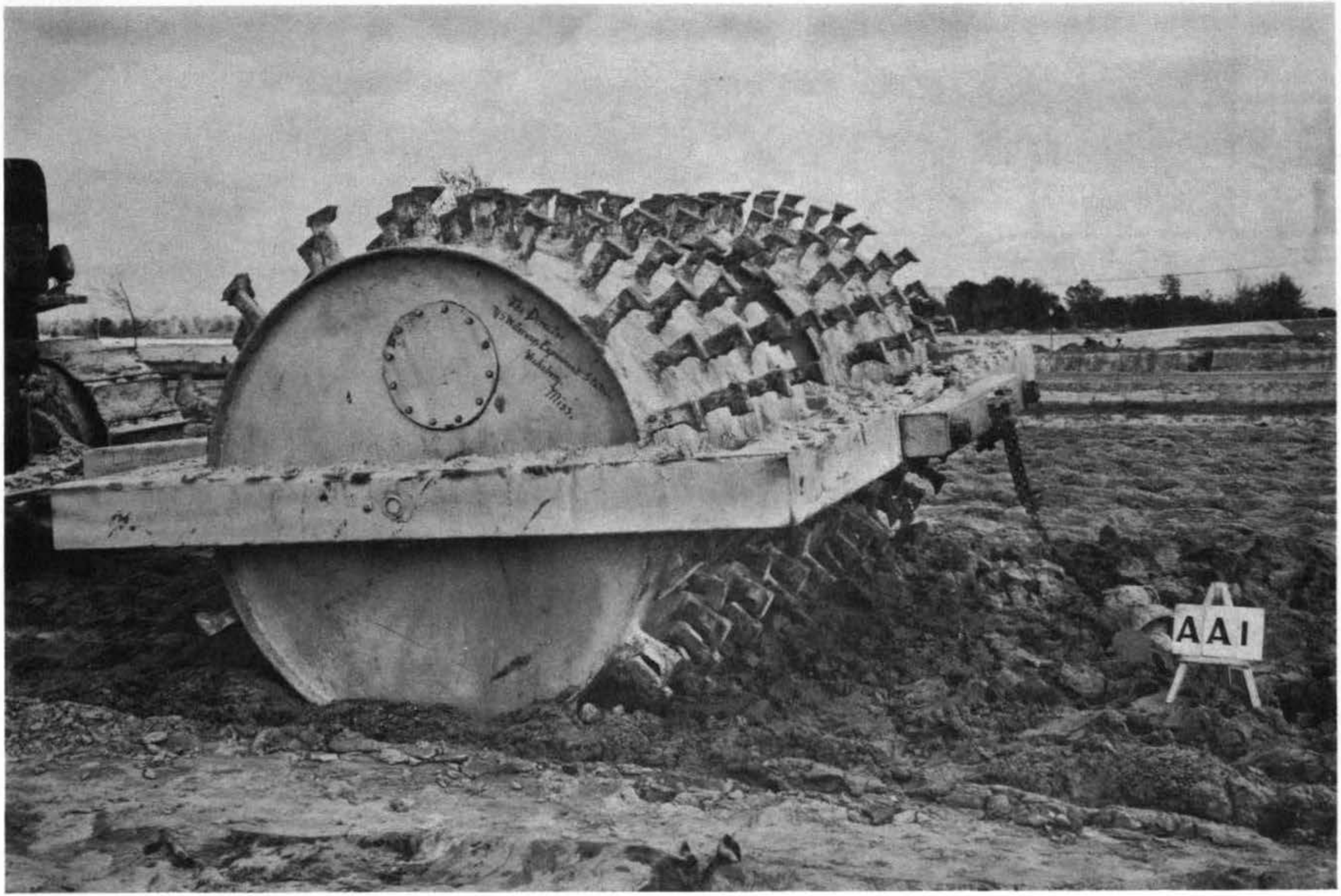
450-psi sheepsfoot roller, first pass, 7-1/2% water content

PHOTOGRAPH 4



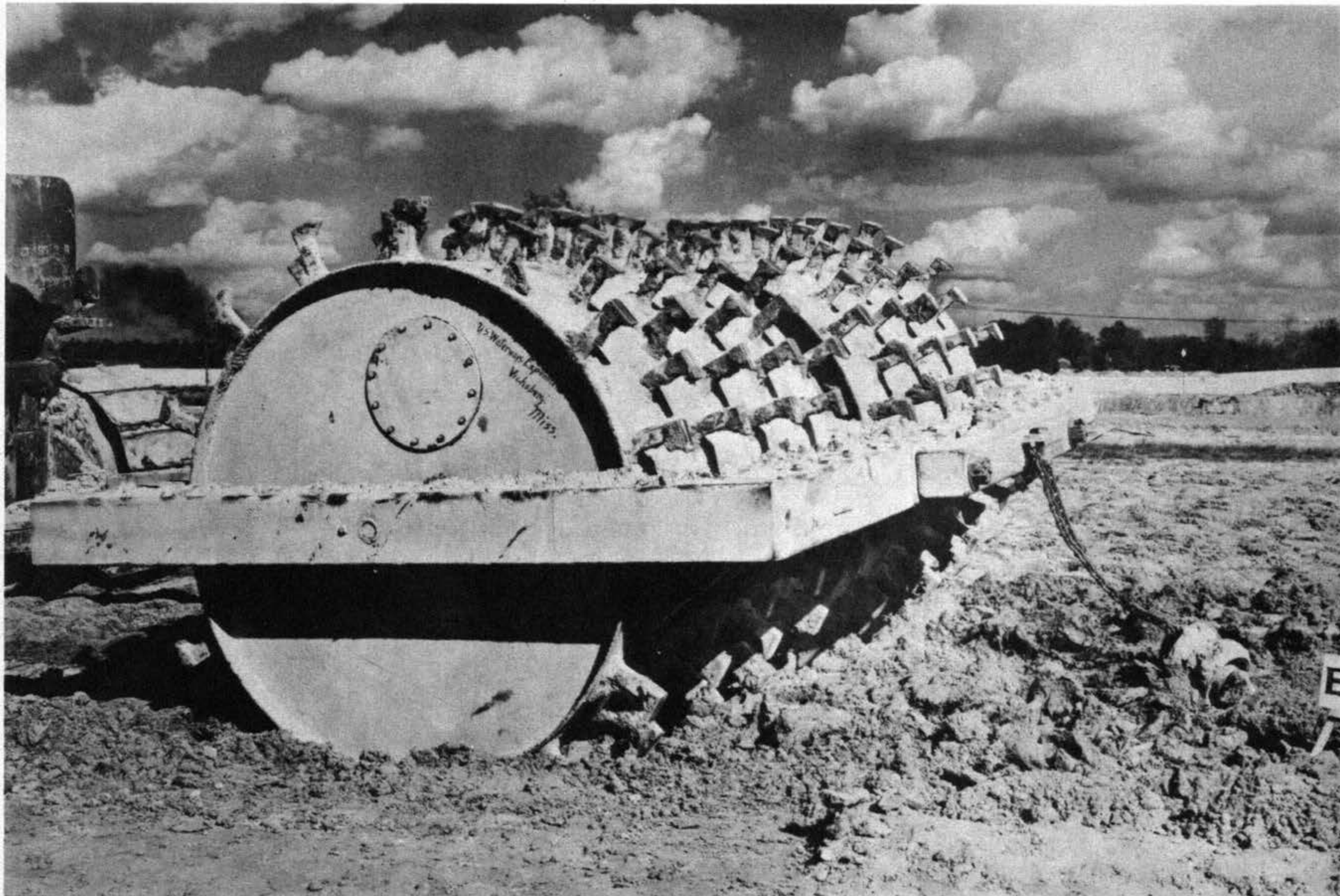
450-psi sheepsfoot roller, first pass, 9% water content

PHOTOGRAPH 5

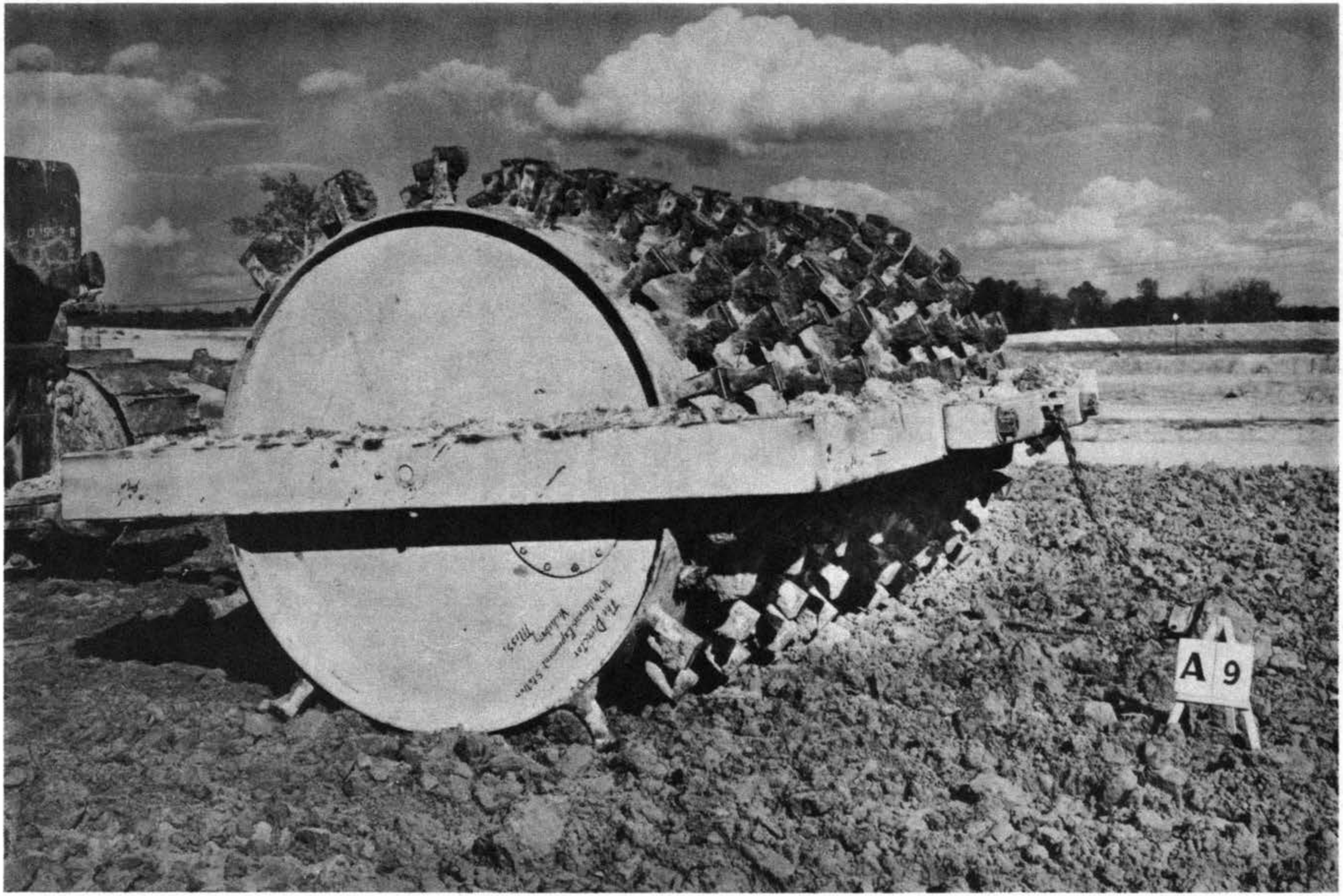


450-psi sheepsfoot roller, first pass, 10-1/2% water content

PHOTOGRAPH 6



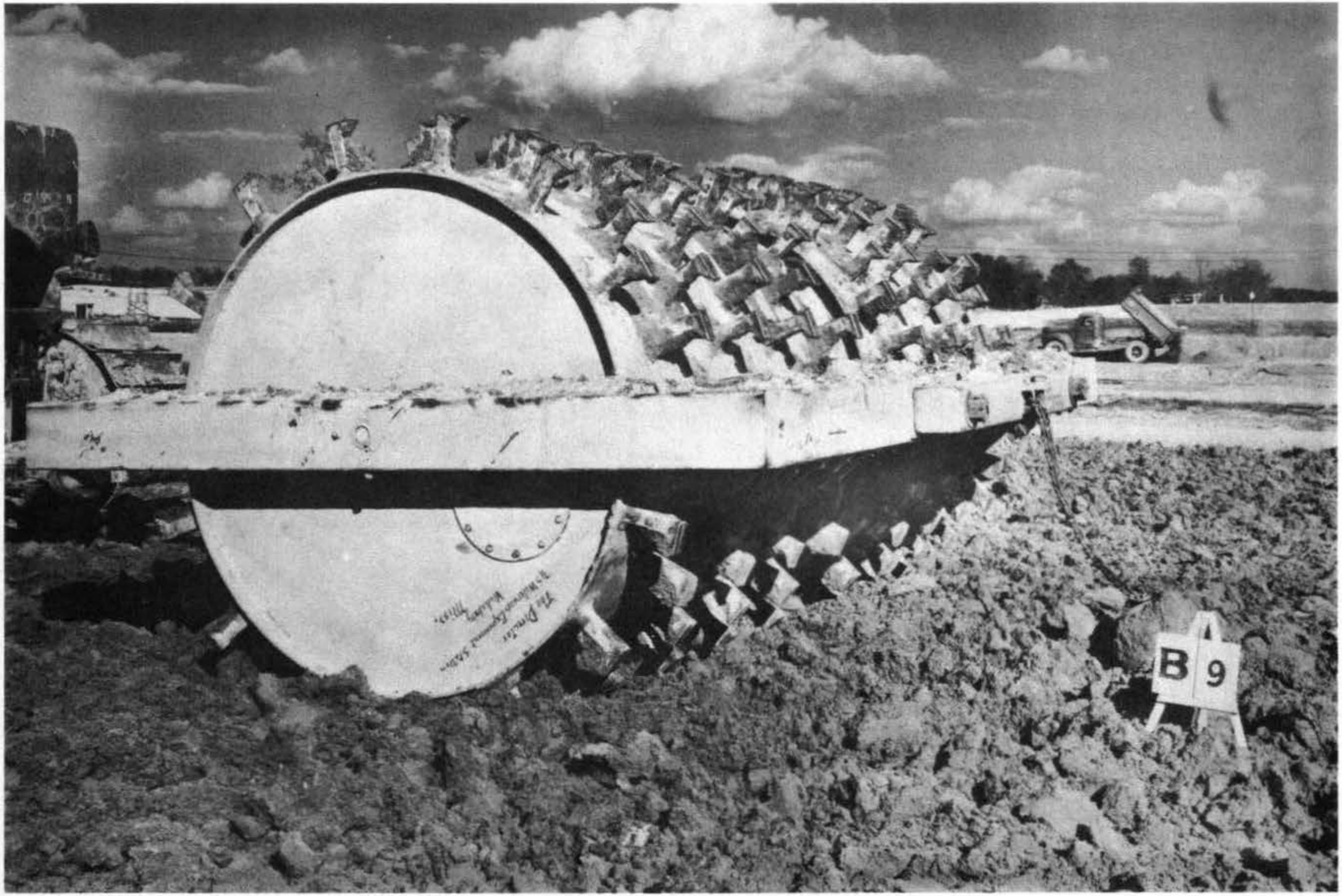
450-psi sheepsfoot roller, first pass, 12% water content



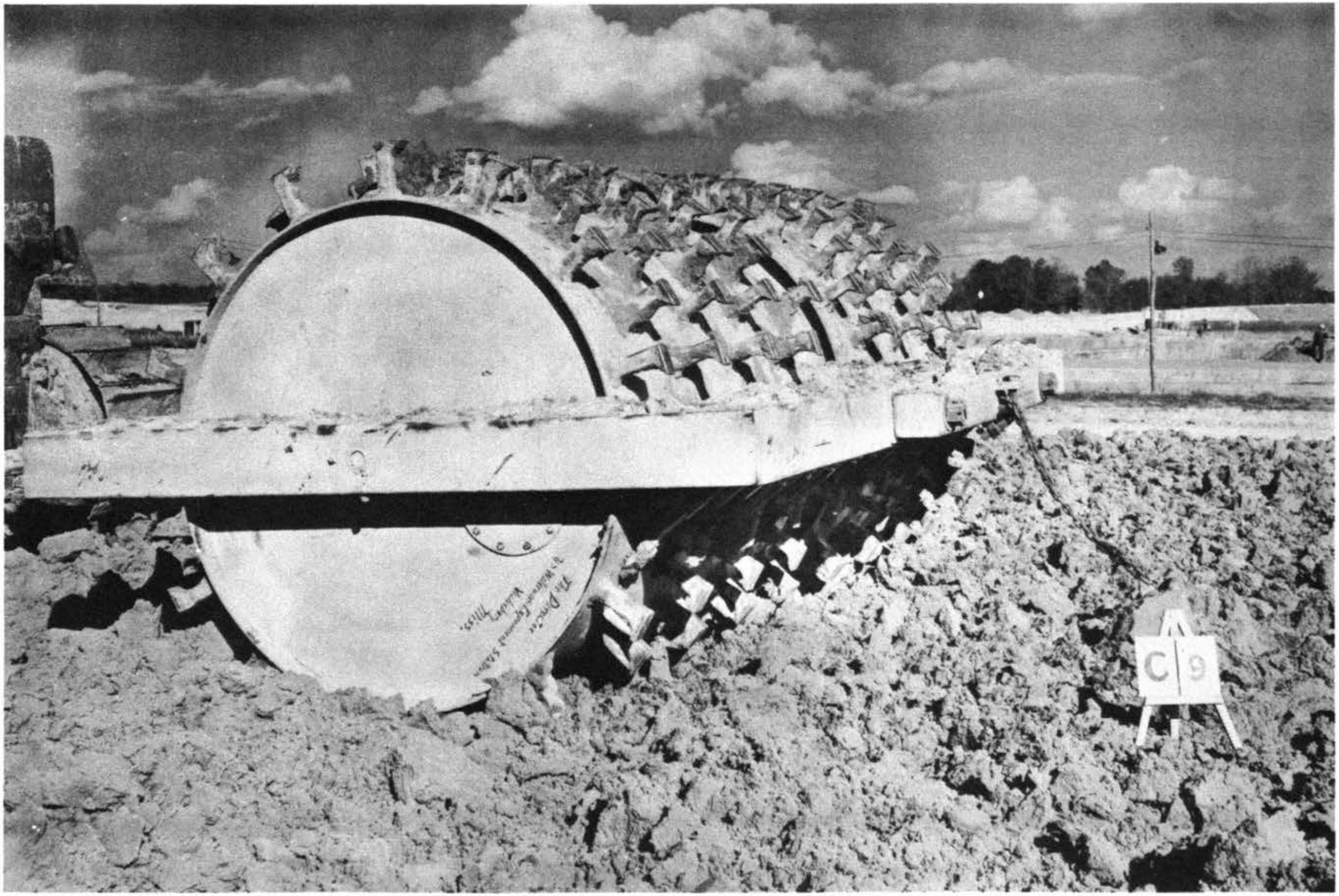
450-psi sheepsfoot roller, ninth pass, 6% water content

PHOTOGRAPH 7

PHOTOGRAPH 8



450-psi sheepsfoot roller, ninth pass, 7-1/2% water content

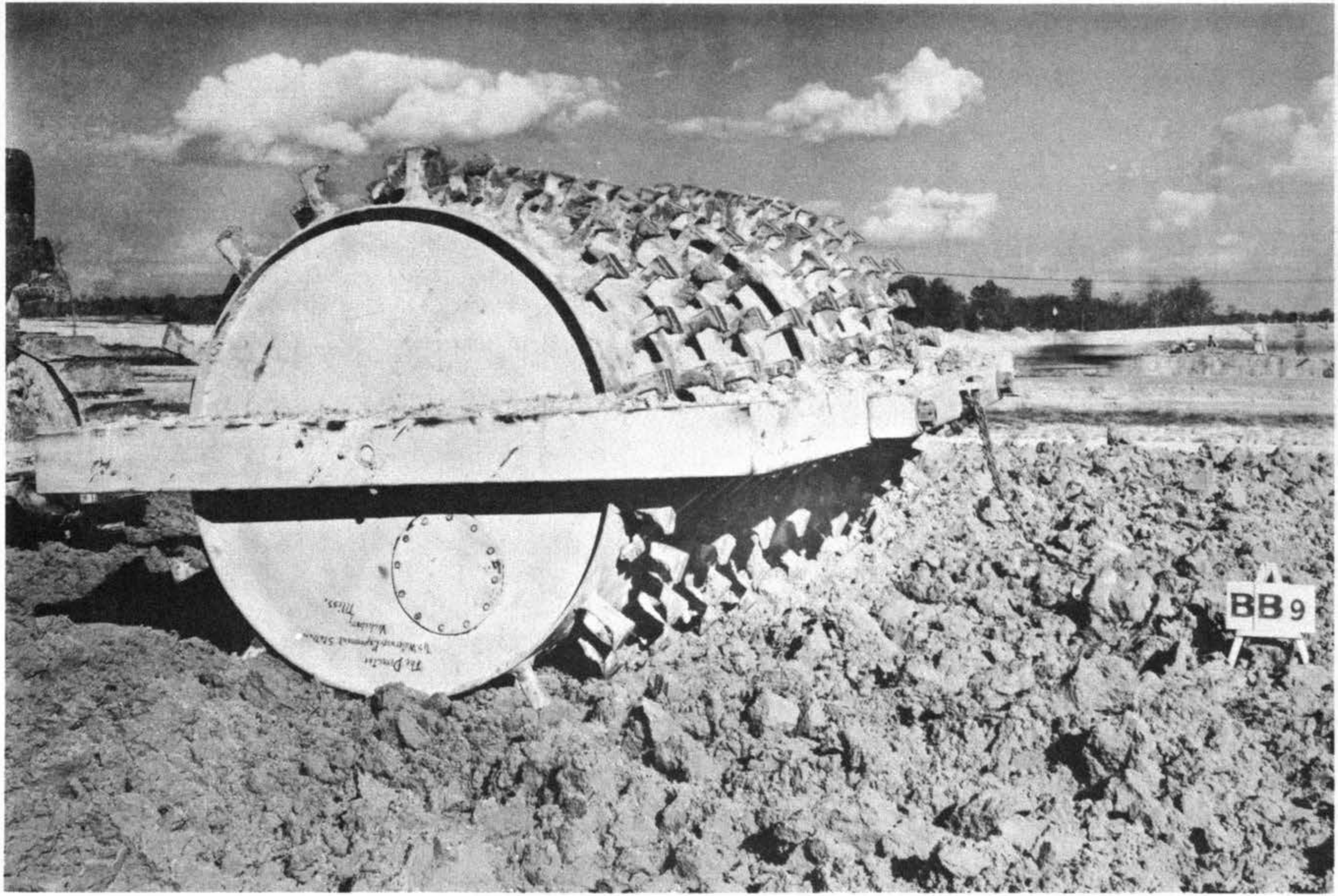


PHOTOGRAPH 9

450-psi sheepsfoot roller, ninth pass, 9% water content

PHOTOGRAPH 10

450-psi sheepsfoot roller, ninth pass, 10-1/2% water content



450-psi sheepsfoot roller, ninth pass, 12% water content

PHOTOGRAPH 11

PHOTOGRAPH 12

40,000-lb wheel load, first coverage, 6% water content

40,000-lb wheel load, first coverage, 8% water content

PHOTOGRAPH 13

PHOTOGRAPH 14

40,000-lb wheel load, first coverage, 10% water content

PHOTOGRAPH 15

40,000-lb wheel load, first coverage, 12% water content

40,000-lb wheel load, first coverage, 14% water content

PHOTOGRAPH 17

40,000-lb wheel load, fourth coverage, 6% water content

PHOTOGRAPH 18

40,000-lb wheel load, fourth coverage, 8% water content

PHOTOGRAPH 19

40,000-lb wheel load, fourth coverage, 10% water content

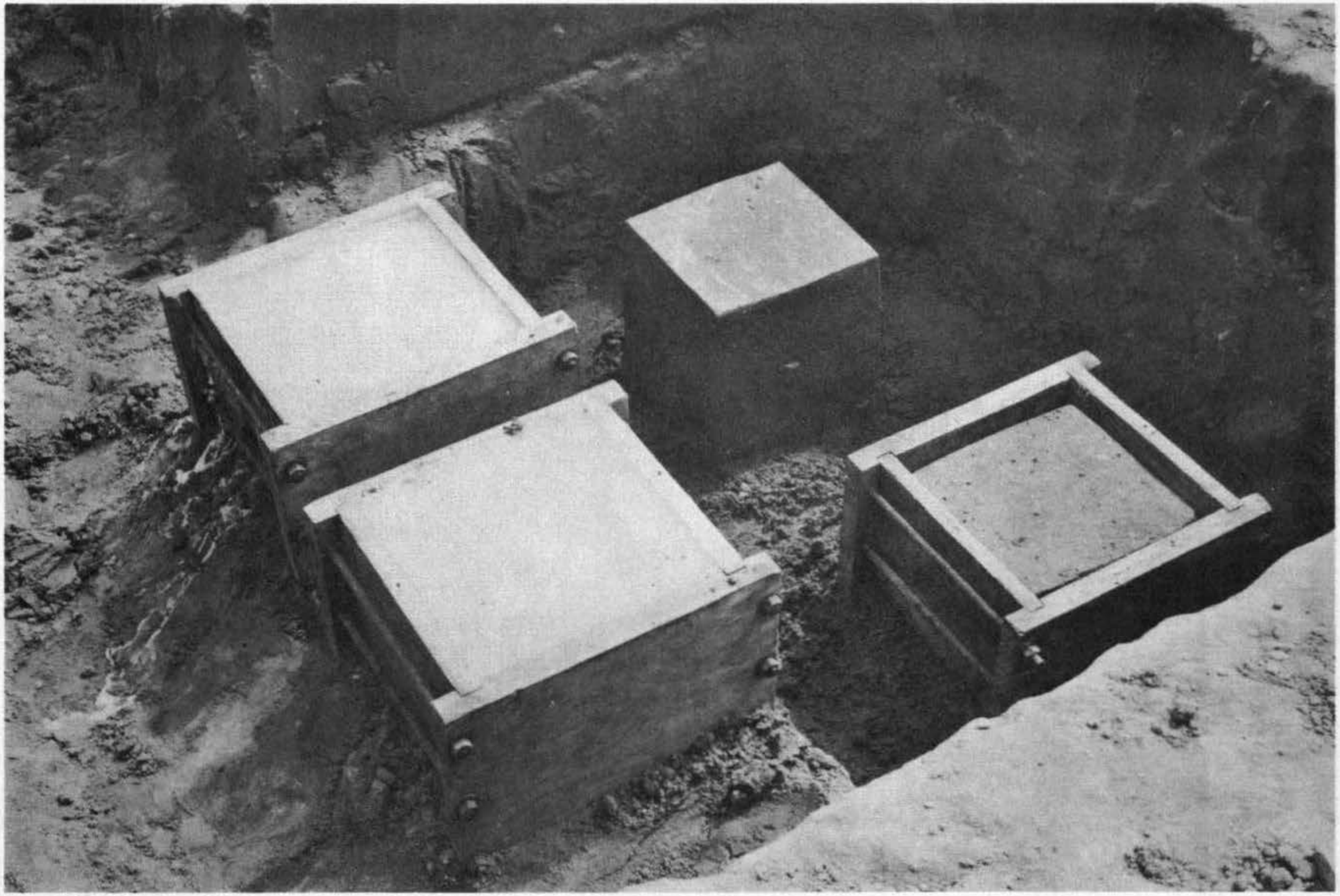
PHOTOGRAPH 20

40,000-lb wheel load, fourth coverage, 12% water content

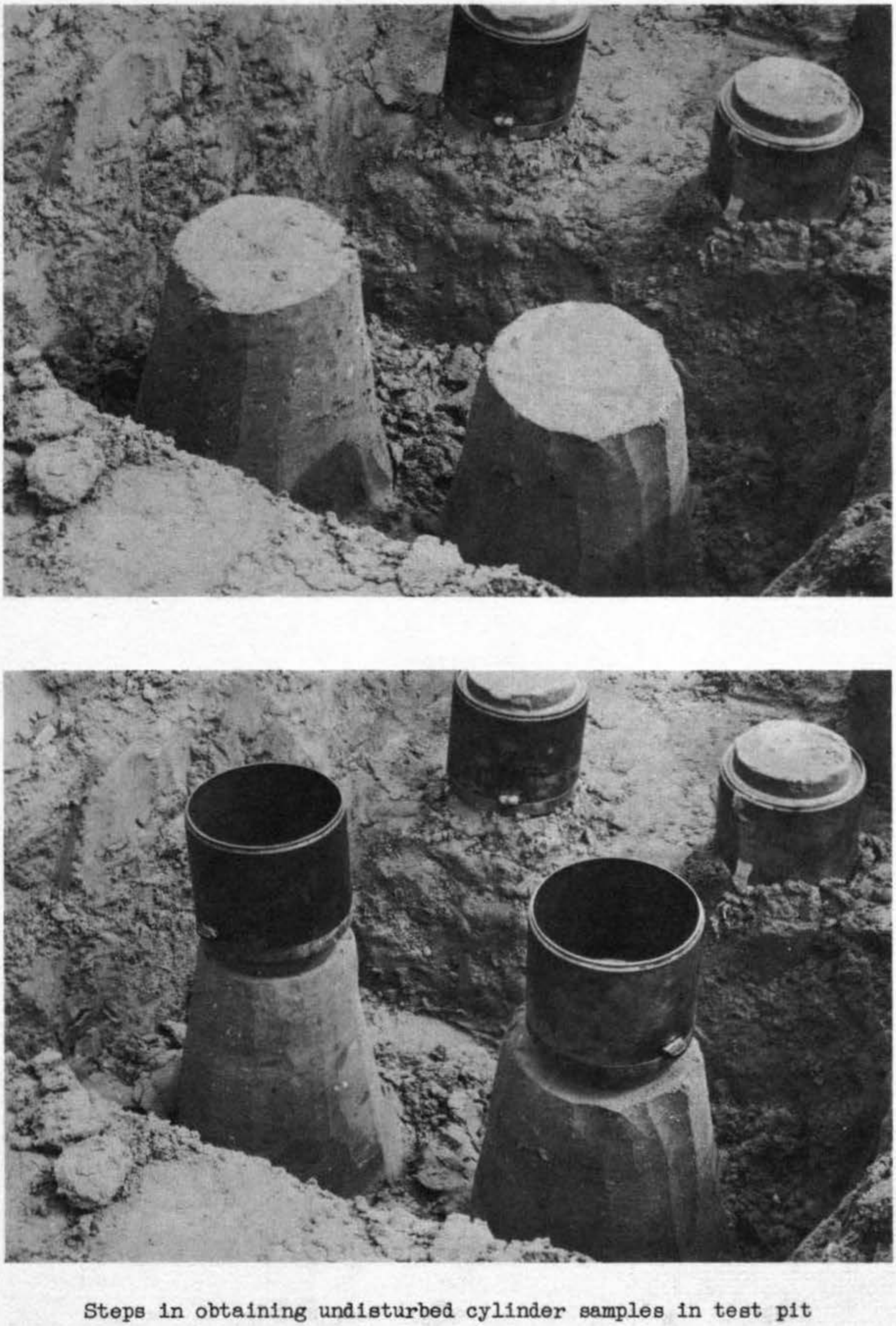
PHOTOGRAPH 21

40,000-lb wheel load, fourth coverage, 14% water content

PHOTOGRAPH 22



Steps in obtaining undisturbed box samples in test pit



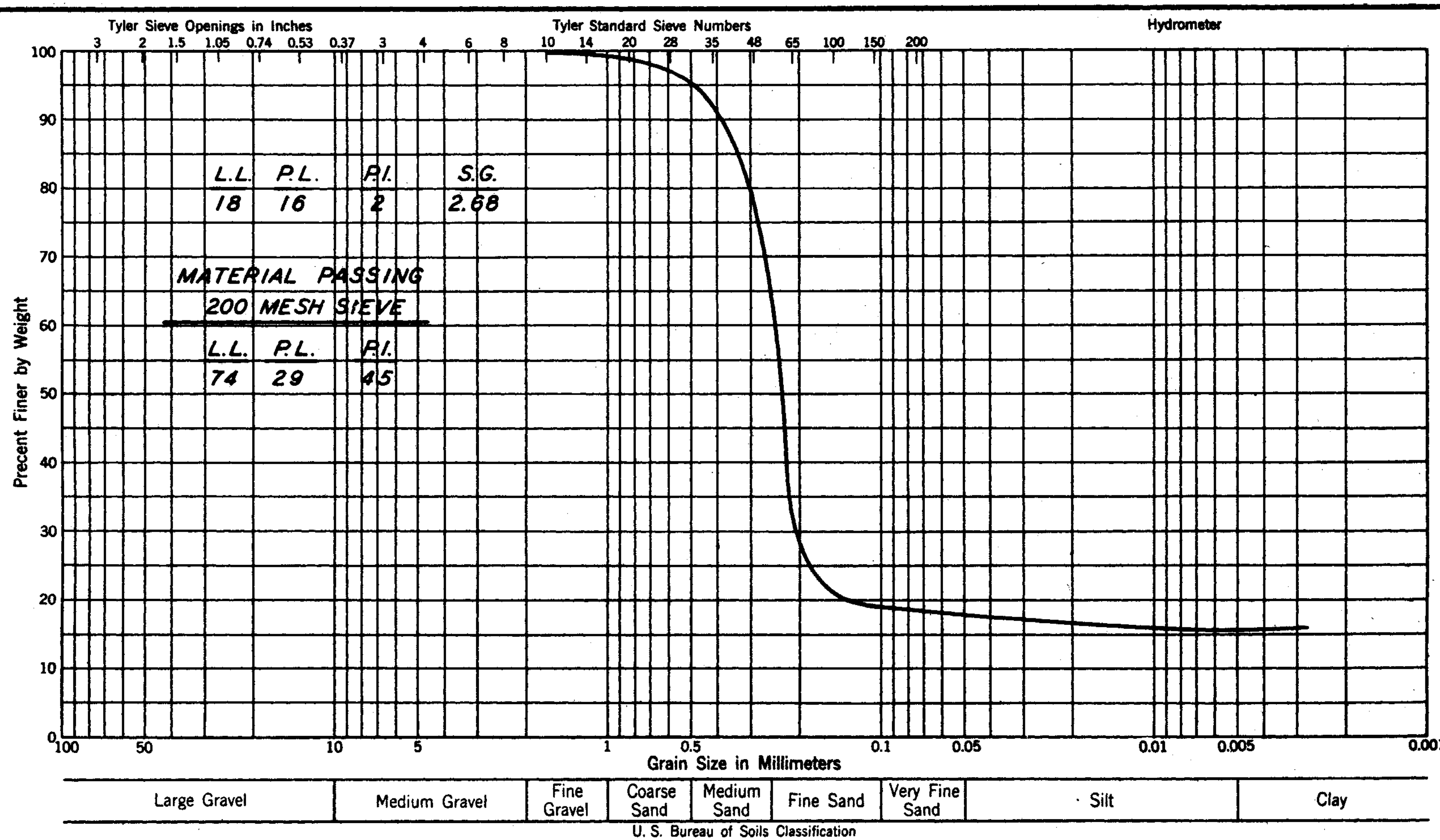
Steps in obtaining undisturbed cylinder samples in test pit

PHOTOGRAPH 23

Steps in obtaining undisturbed cylinder samples in test pit

PHOTOGRAPH 24

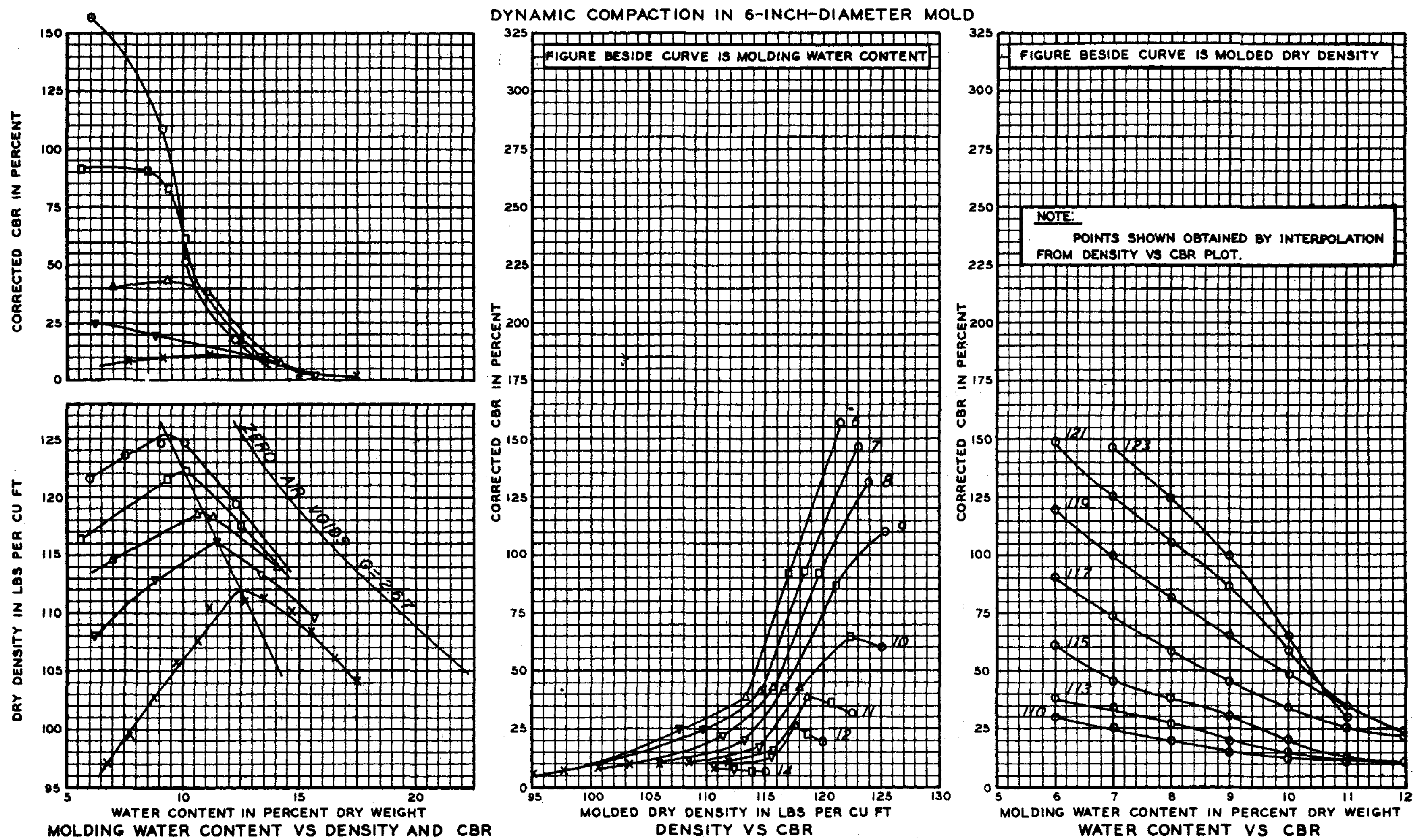
FIGURES



CLASSIFICATION DATA FOR CLAYEY SAND

FIGURE 1

FIGURE 2



LEGEND

	LAYERS	BLOWS PER LAYER	WEIGHT HAMMER	DROP IN INCHES
o	5	100	10 LBS	18
□	5	55	10 LBS	18 (MOD. AASHO)
Δ	5	26	10 LBS	18
▽	5	12	10 LBS	18 *
x	3	12	5.5 LBS	12

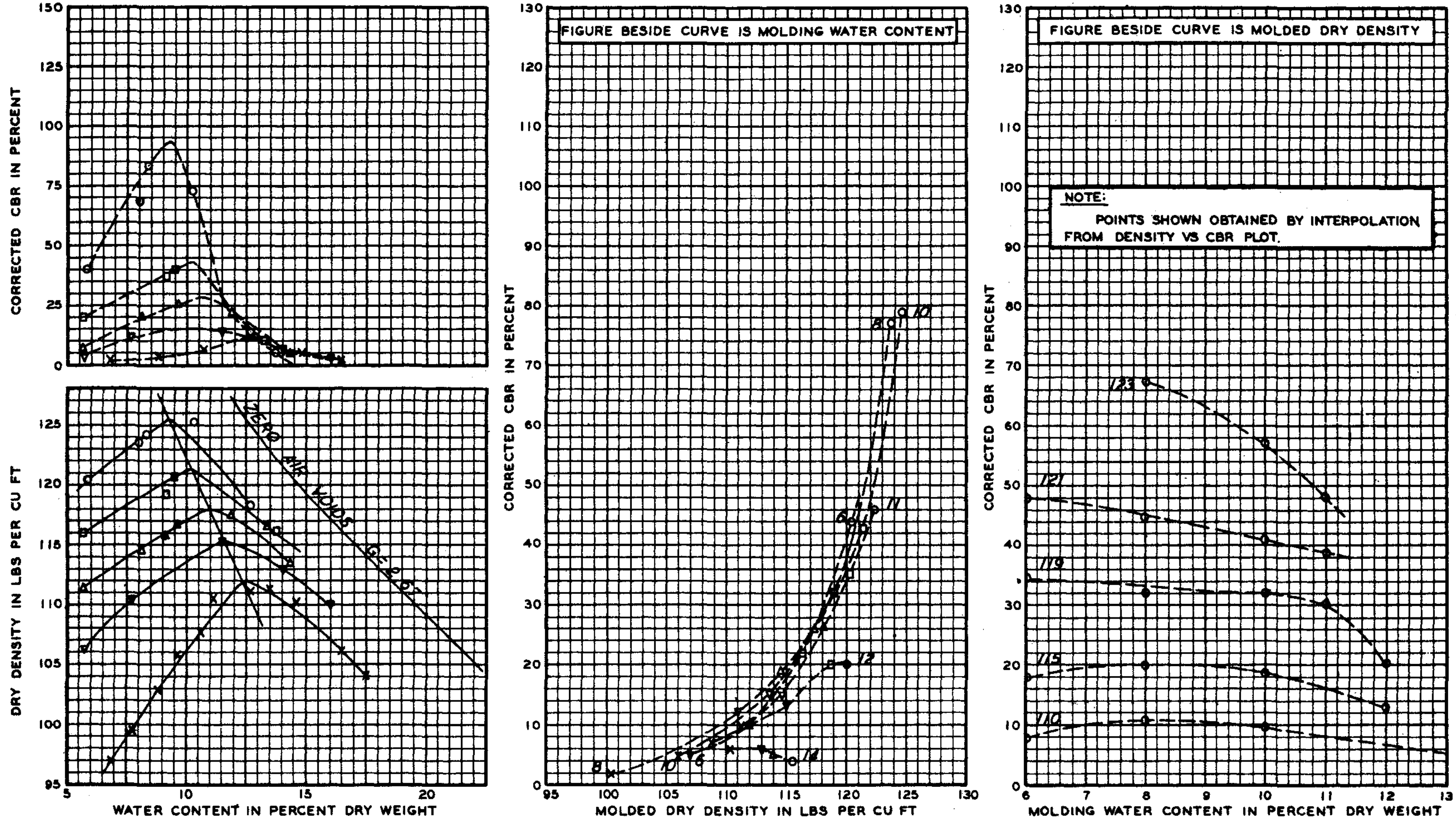
NOTES: SPECIMENS TESTED AS MOLDED (UNSOAKED).

PENETRATION SURCHARGE 10 LBS.

* EQUIV. TO STD. AASHO EFFORT

CBR, DENSITY AND WATER CONTENT DATA
DYNAMIC COMPACTION, AS MOLDED

DYNAMIC COMPACTION IN 6-INCH-DIAMETER MOLD



MOLDING WATER CONTENT VS DENSITY AND CBR — DENSITY VS CBR — WATER CONTENT VS CBR

LEGEND

	LAYERS	BLOWS PER LAYER	WEIGHT HAMMER	DROP IN INCHES
o	5	100	10 LBS	18
□	5	55	10 LBS	18 (MOD. AASHO)
Δ	5	26	10 LBS	18
▼	5	12	10 LBS	18*
x	3	12	5.5 LBS	12

NOTES: SPECIMENS SOAKED FROM TOP AND BOTTOM.

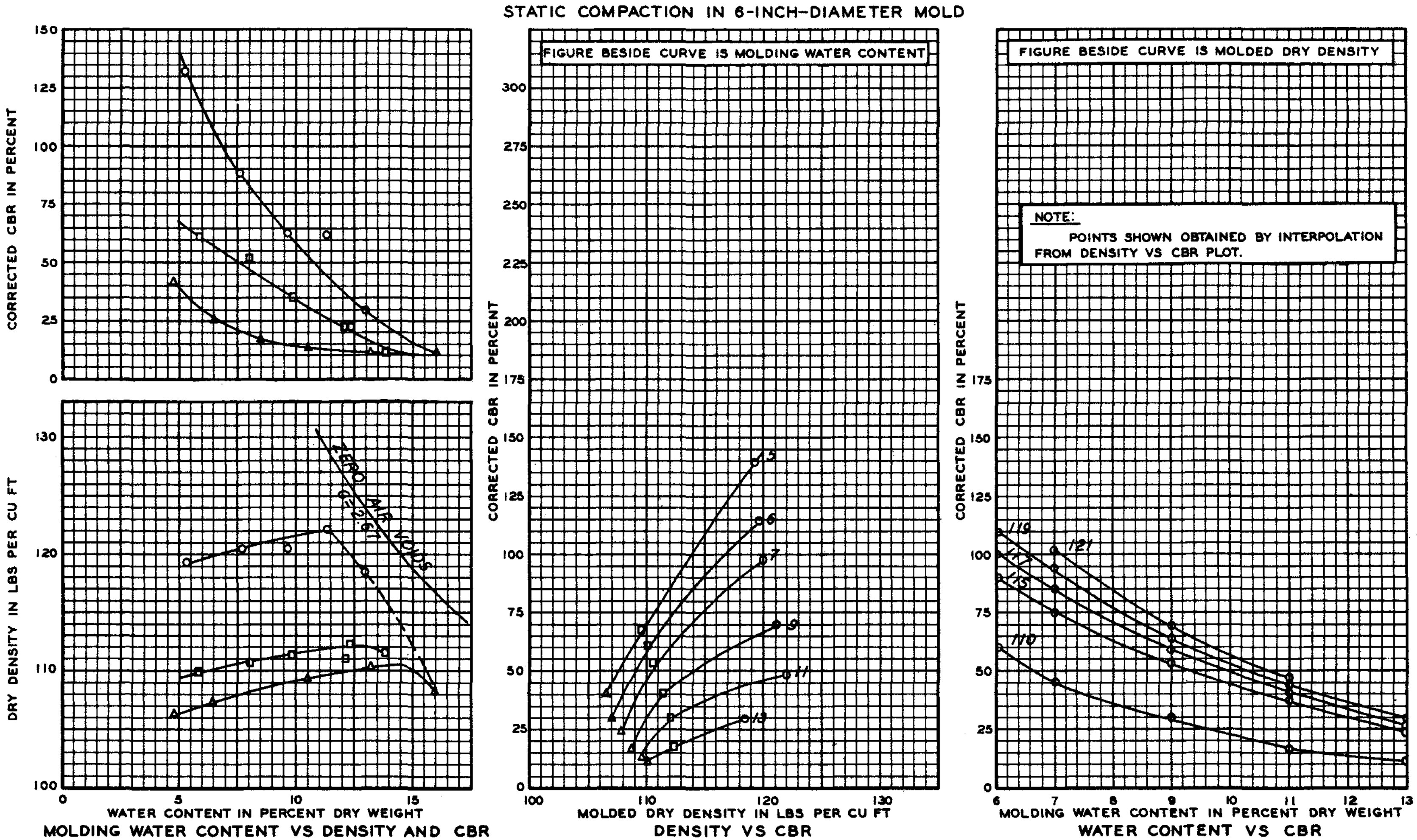
SOAKING AND PENETRATION SURCHARGE 10 LBS.

* EQUIV. TO STD. AASHO EFFORT

CBR, DENSITY AND WATER CONTENT DATA, DYNAMIC COMPACTION, SOAKED

FIGURE 3

FIGURE 4



LEGEND

○——— 4000 PSI

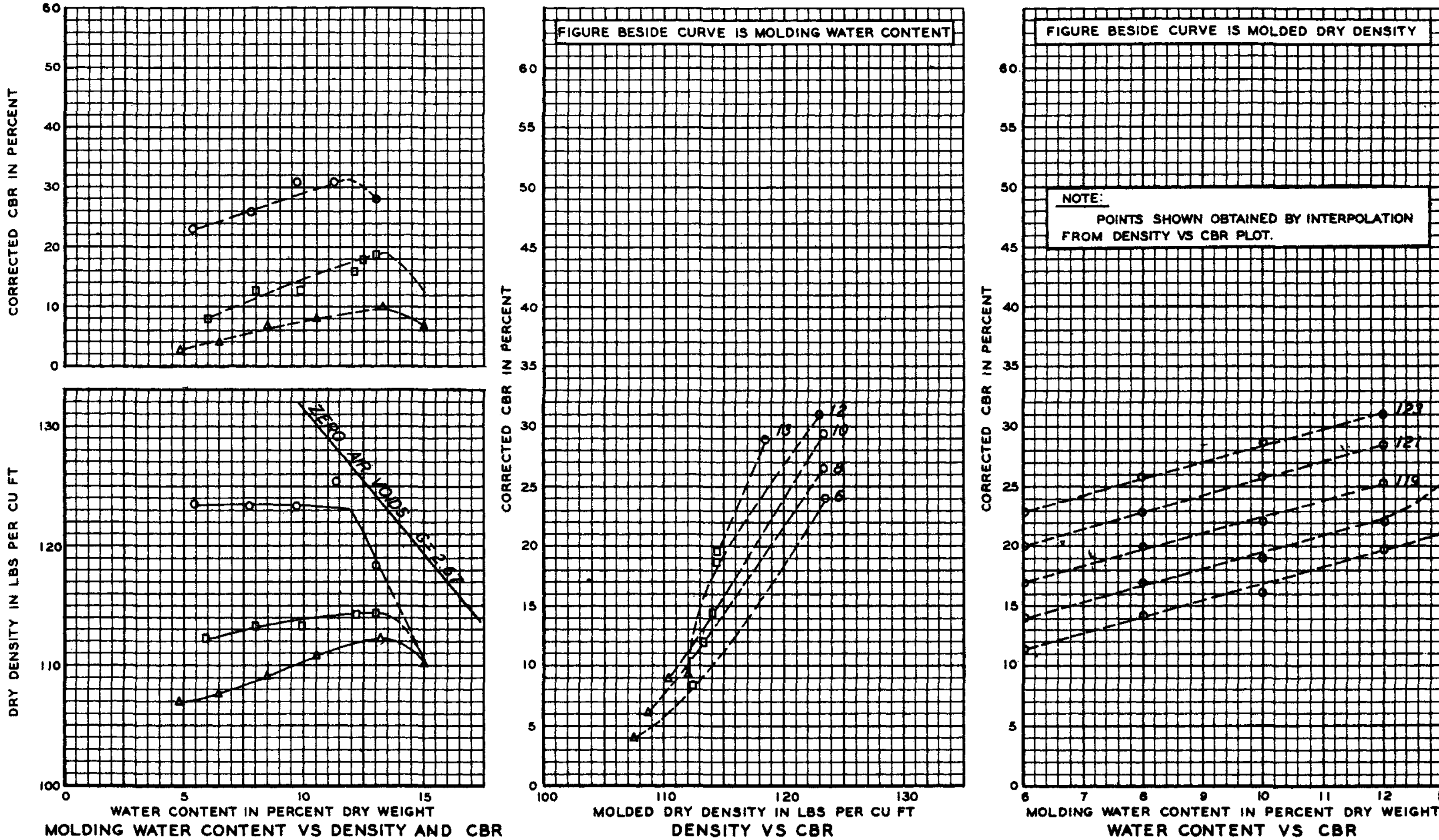
□——— 2000 PSI

△——— 1000 PSI

NOTES: SPECIMENS TESTED AS MOLDED (UNSOAKED)
PENETRATION SURCHARGE 10 LBS.
STATIC LOAD APPLIED FROM ONE END ONLY.

CBR, DENSITY AND WATER CONTENT DATA
STATIC COMPACTION, AS MOLDED

STATIC COMPACTION IN 6-INCH-DIAMETER MOLD



LEGEND

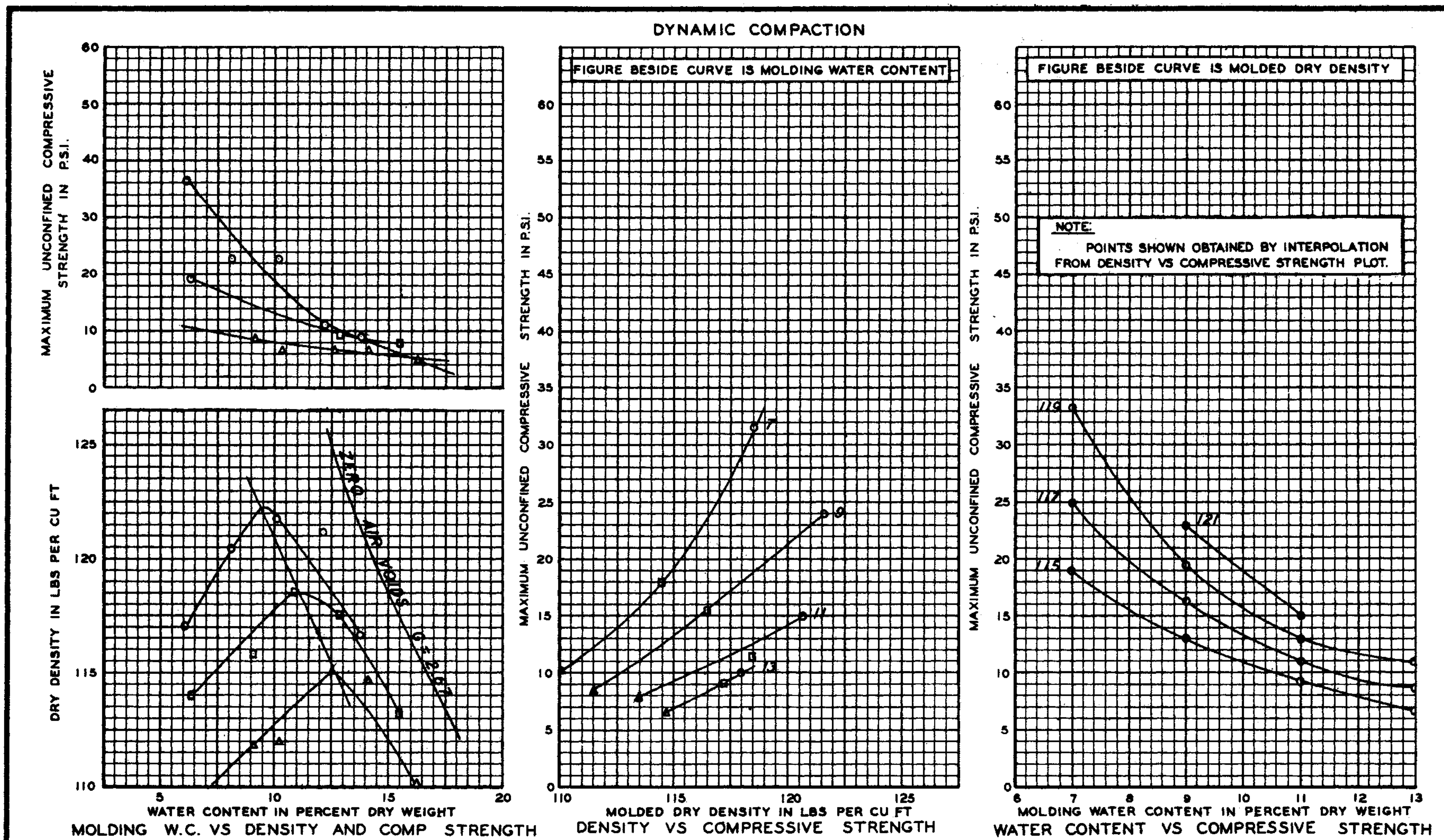
- ○ 4000 PSI
- □ 2000 PSI
- △ 1000 PSI

NOTES: SPECIMENS SOAKED FROM TOP AND BOTTOM.
SOAKING AND PENETRATION SURCHARGE 10 LBS
STATIC LOAD APPLIED FROM EACH END OF SAMPLE.

CBR, DENSITY AND WATER CONTENT DATA, STATIC COMPACTION, SOAKED

FIGURE 5

FIGURE 6

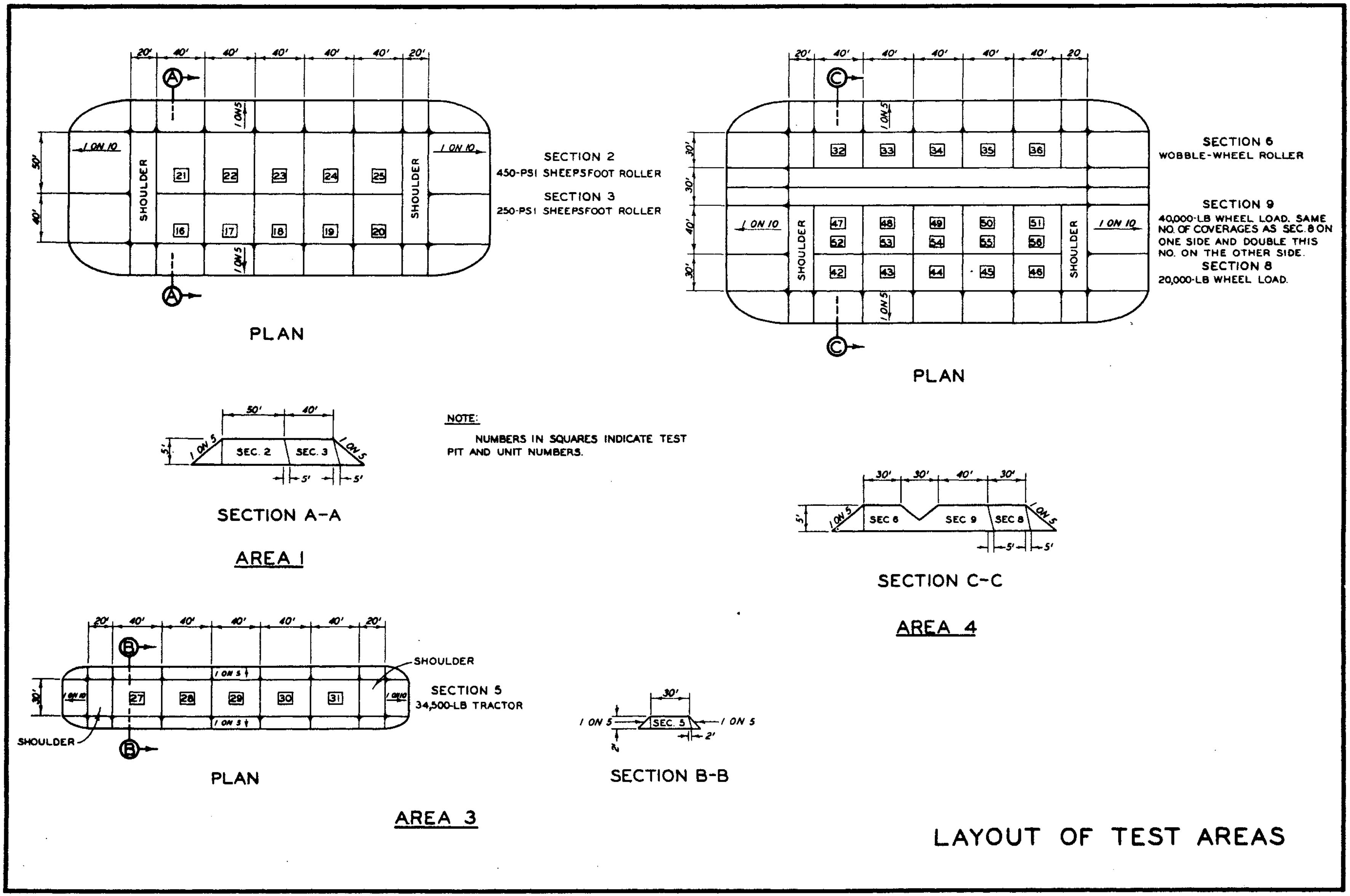


LEGEND

	LAYERS	BLOWS PER LAYER	WEIGHT HAMMER	DROP IN INCHES
O ——	5	58	5.5	12
□ ——	5	27	5.5	12
Δ ——	5	13	5.5	12

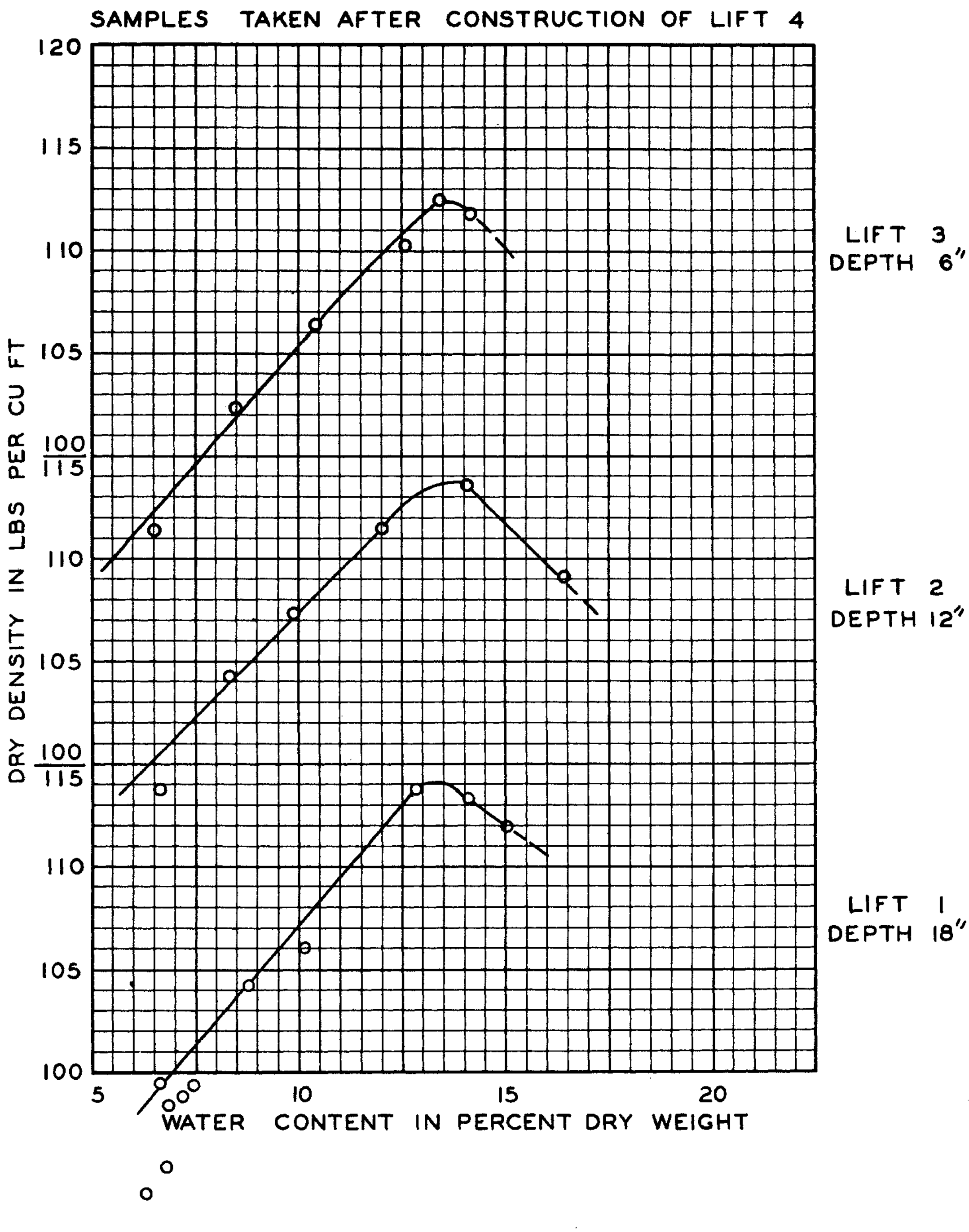
NOTES: SPECIMENS COMPACTED IN 3.0-INCH-DIAMETER MOLD.
TESTED AS MOLDED (UNSOAKED).

VARIATION OF UNCONFINED COMPRESSIVE STRENGTH WITH DENSITY AND WATER CONTENT



LAYOUT OF TEST AREAS

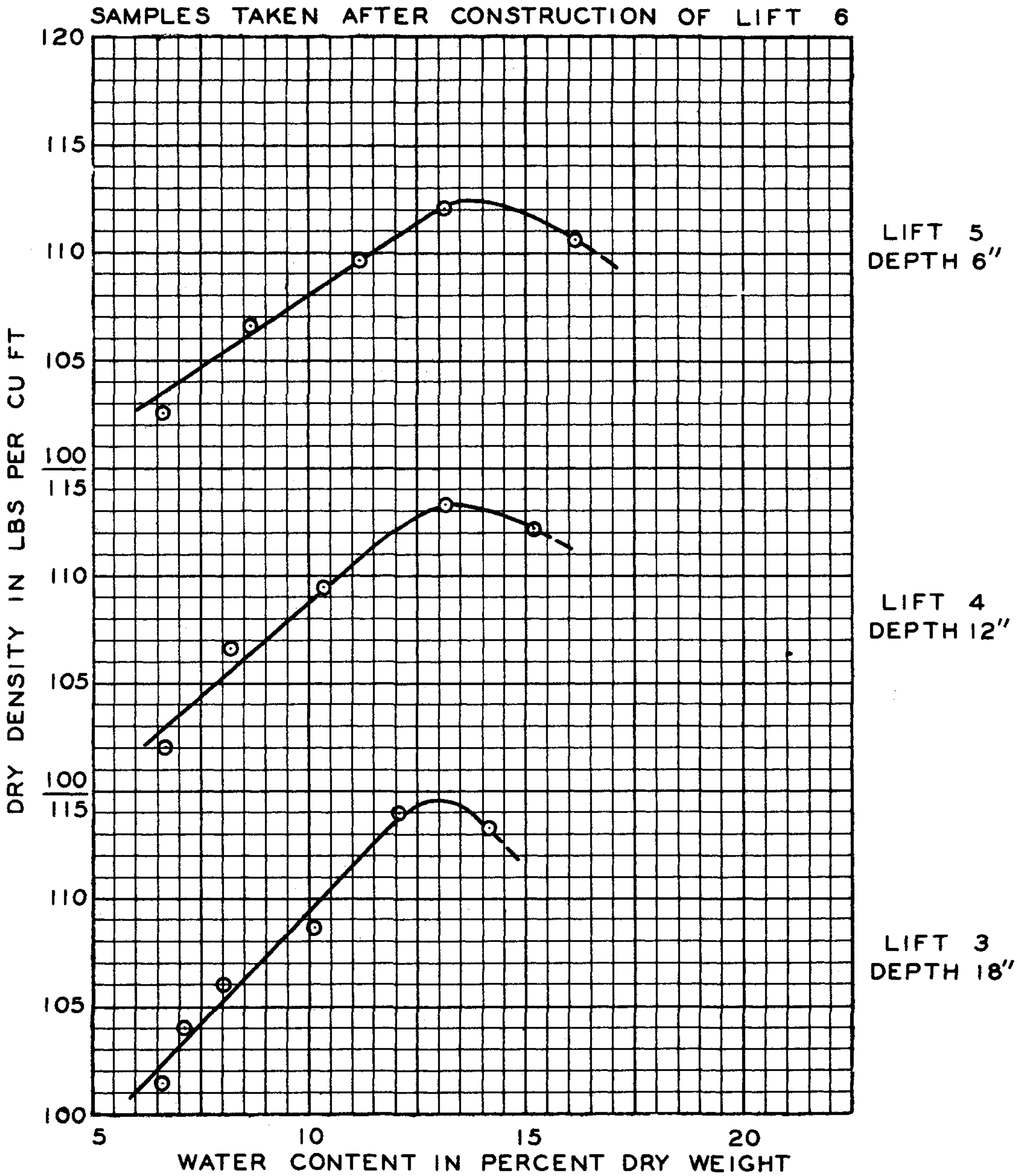
FIGURE 7



TYPICAL MOISTURE-DENSITY DATA
FROM CONSTRUCTION LIFTS

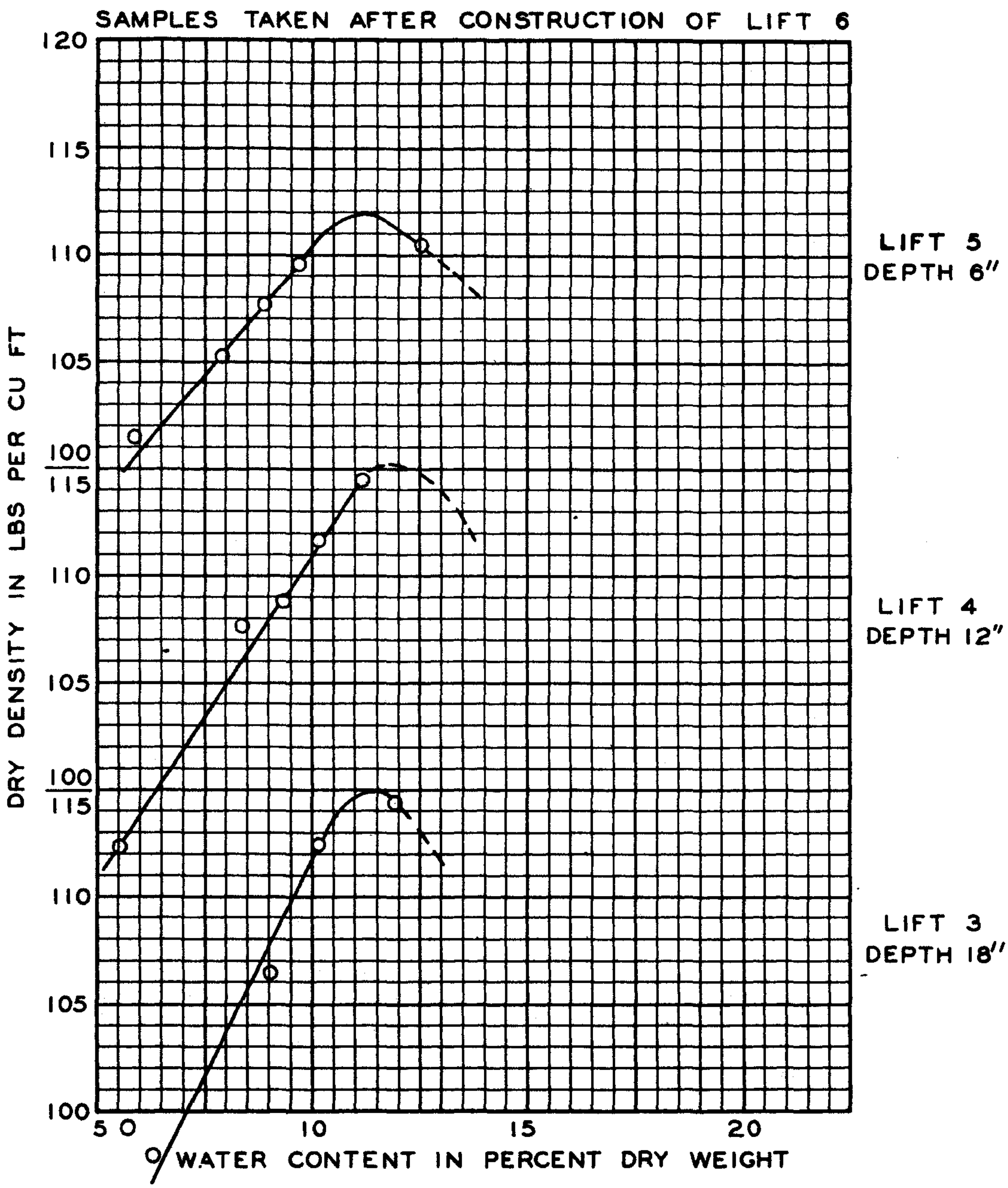
SECTION 5 - 34,500-LB TRACTOR - 3 COVERAGES

FIGURE 8



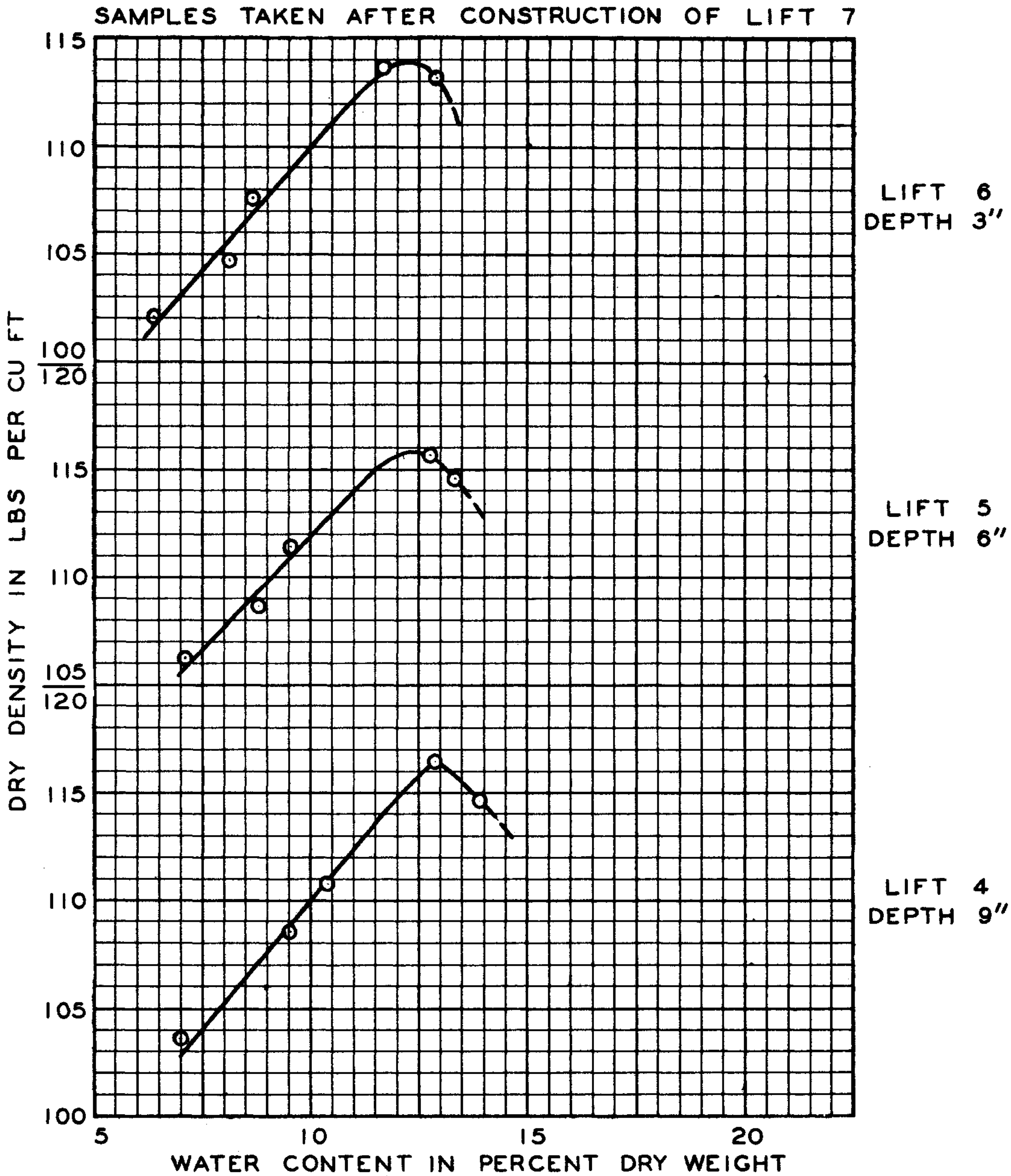
TYPICAL MOISTURE-DENSITY DATA
FROM CONSTRUCTION LIFTS
SECTION 3 - 250-PSI SHEEPSFOOT ROLLER - 9 PASSES

FIGURE 9



TYPICAL MOISTURE–DENSITY DATA
FROM CONSTRUCTION LIFTS
SECTION 2 –450–PSI SHEEPSFOOT ROLLER – 9 PASSES

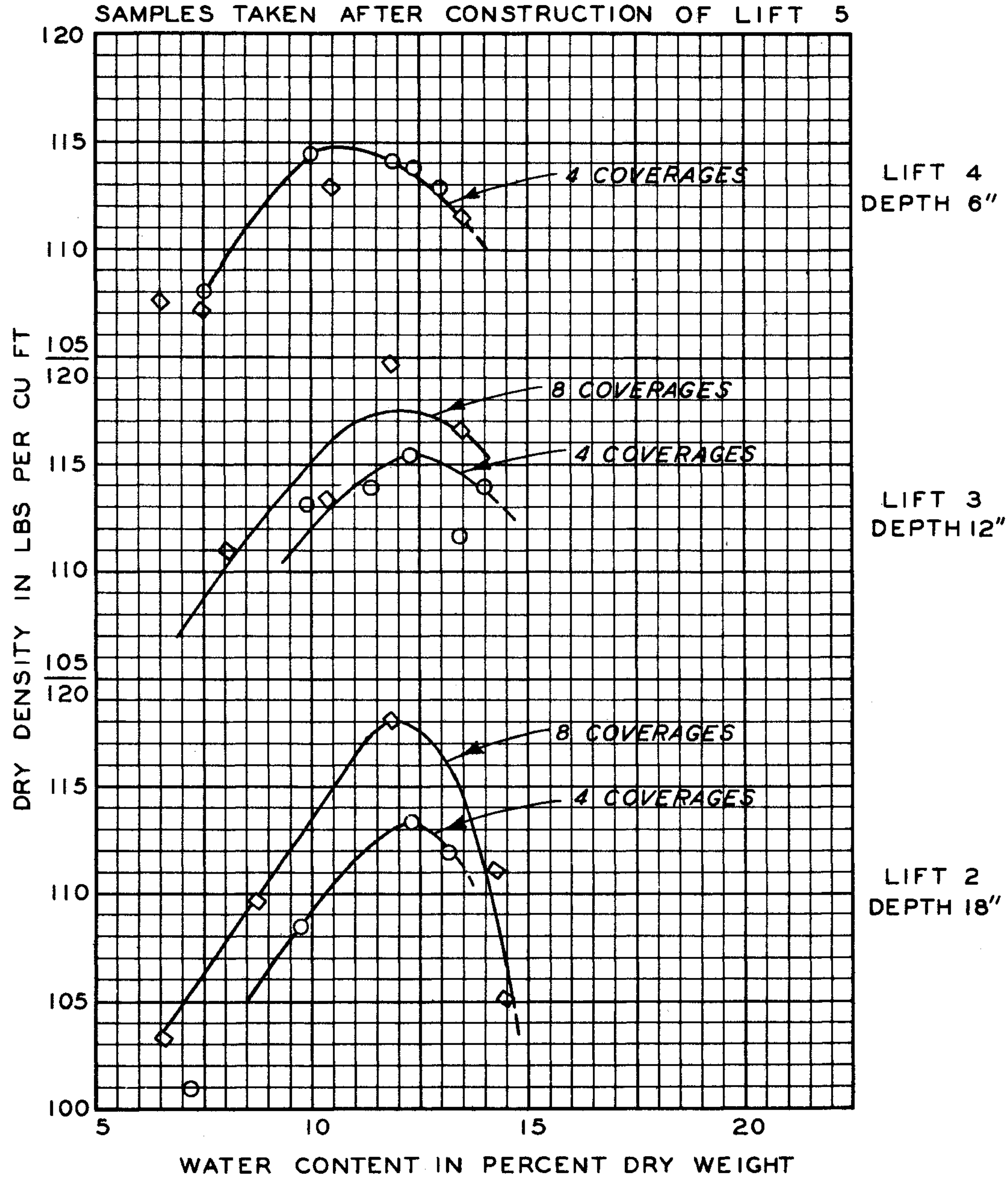
FIGURE 10



TYPICAL MOISTURE-DENSITY DATA
FROM CONSTRUCTION LIFTS

SECTION 6 - 1,500-LB WOBBLE-WHEEL LOAD - 6 COVERAGES

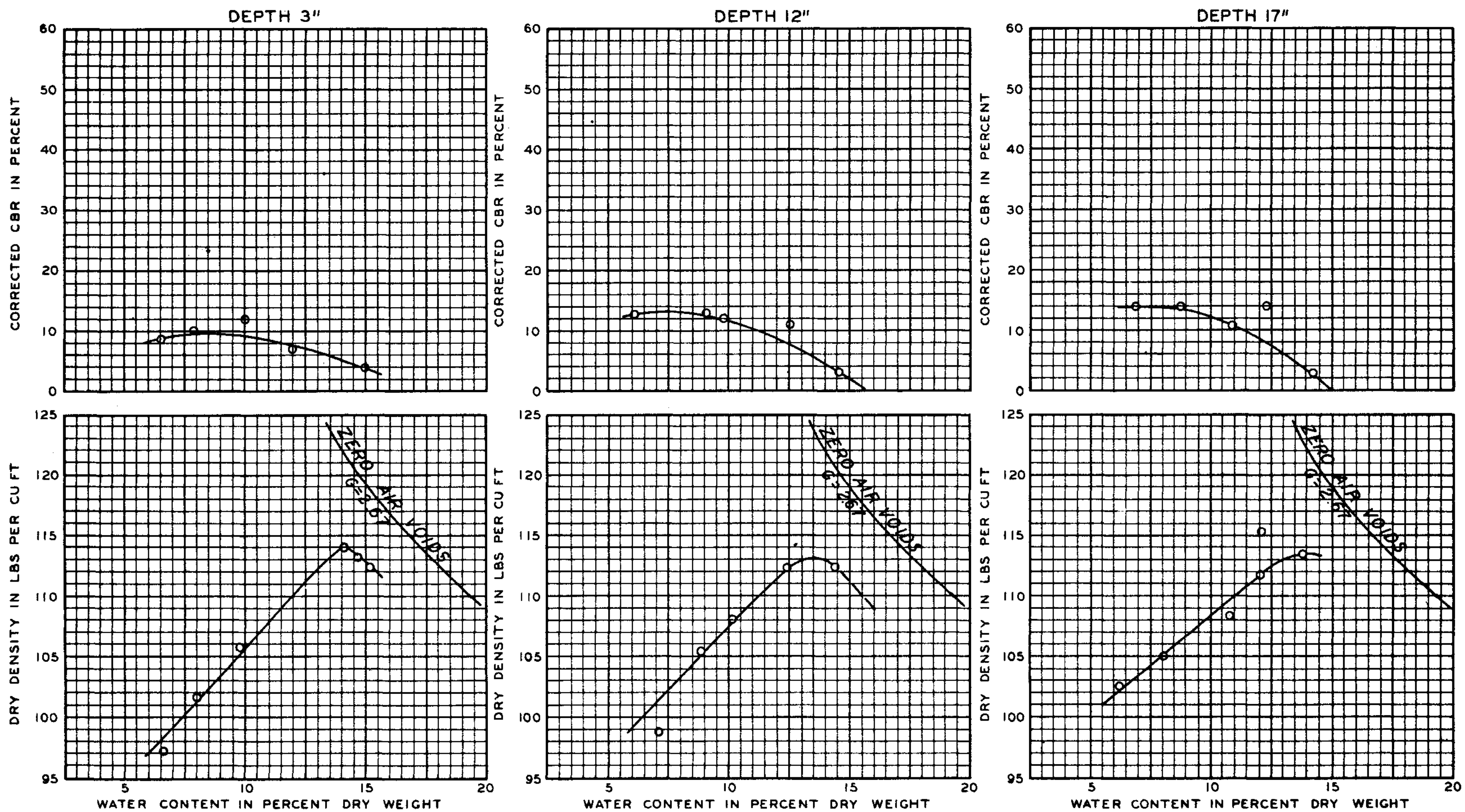
FIGURE 11



TYPICAL MOISTURE-DENSITY DATA
FROM CONSTRUCTION LIFTS

SECTION 9-40,000-LB WHEEL LOAD-4 AND 8 COVERAGES

FIGURE 12



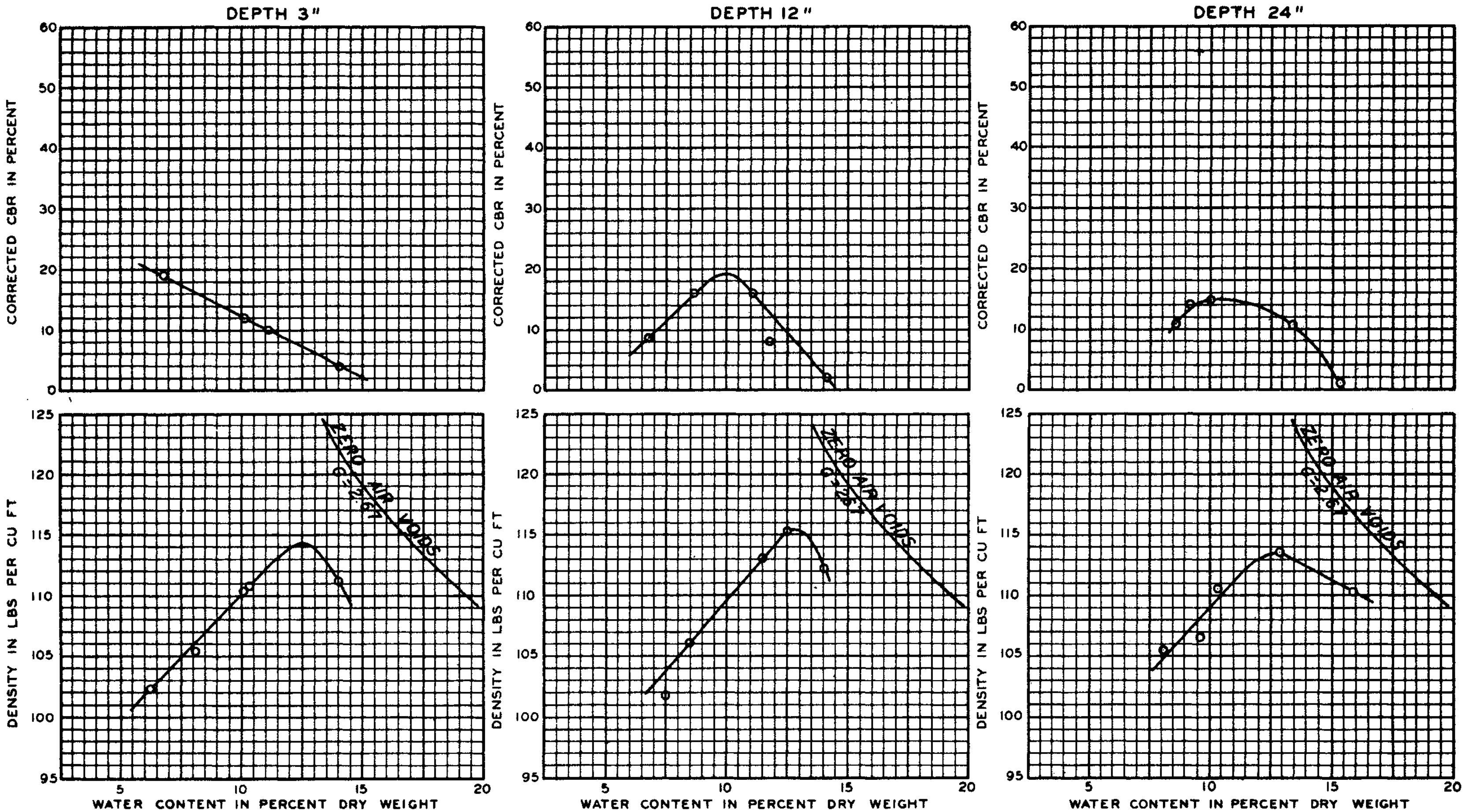
NOTES: WATER CONTENT VALUES USED IN CBR VS WATER CONTENT PLOTS WERE OBTAINED FROM DISTURBED SAMPLES TAKEN IMMEDIATELY BENEATH CBR PENETRATION PISTON.

WATER CONTENT AND DENSITY VALUES USED IN WATER CONTENT VS DENSITY PLOTS WERE OBTAINED FROM UNDISTURBED VOLUMETRIC SAMPLES TAKEN IMMEDIATELY ADJACENT TO CBR TEST.

VARIATION OF FIELD IN-PLACE CBR AND DENSITY WITH WATER CONTENT
SECTION 5-34,500-LB TRACTOR-3 COVERAGES

FIGURE 13

FIGURE 14

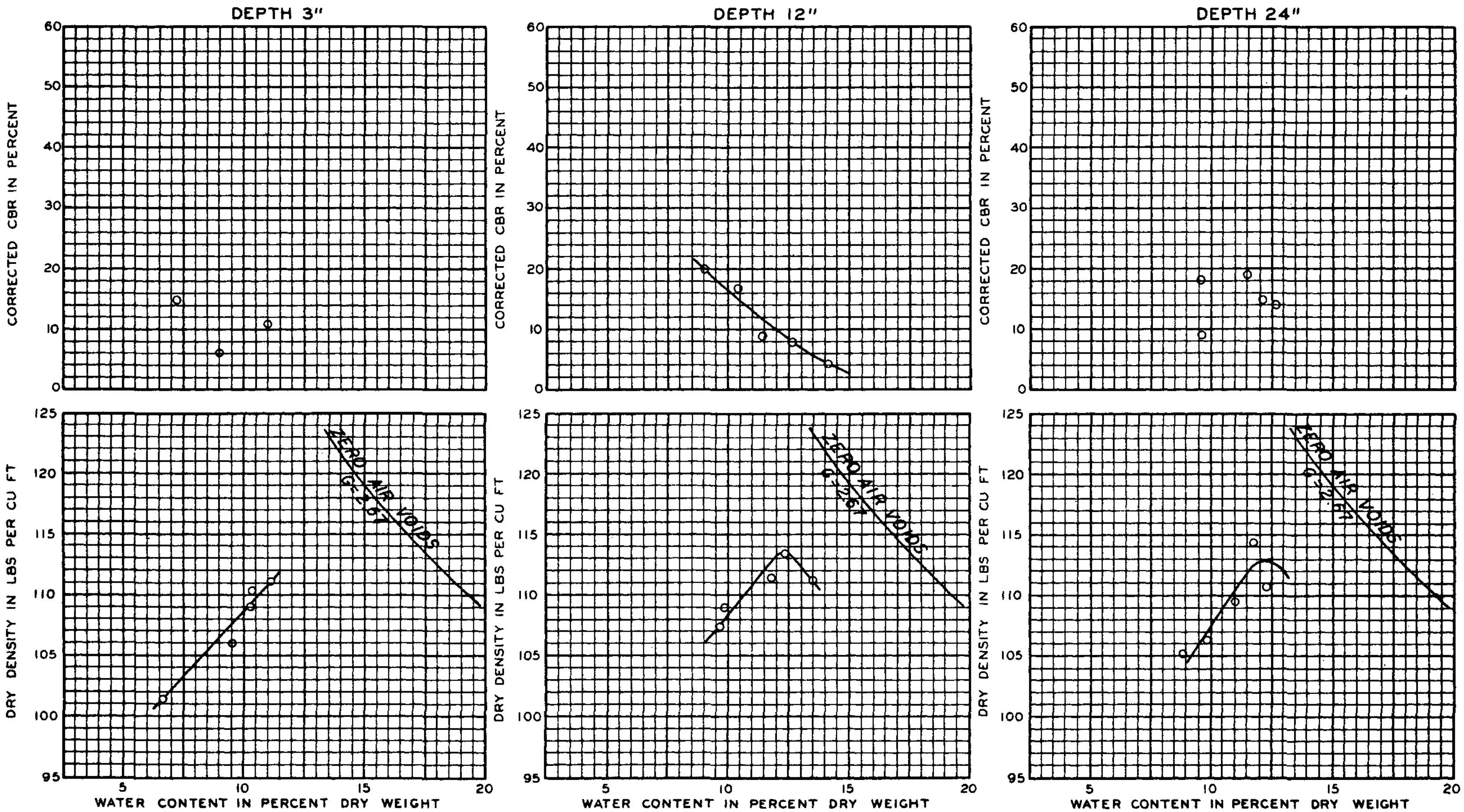


NOTES: WATER CONTENT VALUES USED IN CBR VS WATER CONTENT PLOTS WERE OBTAINED FROM DISTURBED SAMPLES TAKEN IMMEDIATELY BENEATH CBR PENETRATION PISTON.

WATER CONTENT AND DENSITY VALUES USED IN WATER CONTENT VS DENSITY PLOTS WERE OBTAINED FROM UNDISTURBED VOLUMETRIC SAMPLES TAKEN IMMEDIATELY ADJACENT TO CBR TEST.

VARIATION OF FIELD IN-PLACE CBR AND DENSITY WITH WATER CONTENT

SECTION 3 - 250-PSI SHEEPSFOOT ROLLER - 9 PASSES



NOTES: WATER CONTENT VALUES USED IN CBR VS WATER CONTENT PLOTS WERE OBTAINED FROM DISTURBED SAMPLES TAKEN IMMEDIATELY BENEATH CBR PENETRATION PISTON.

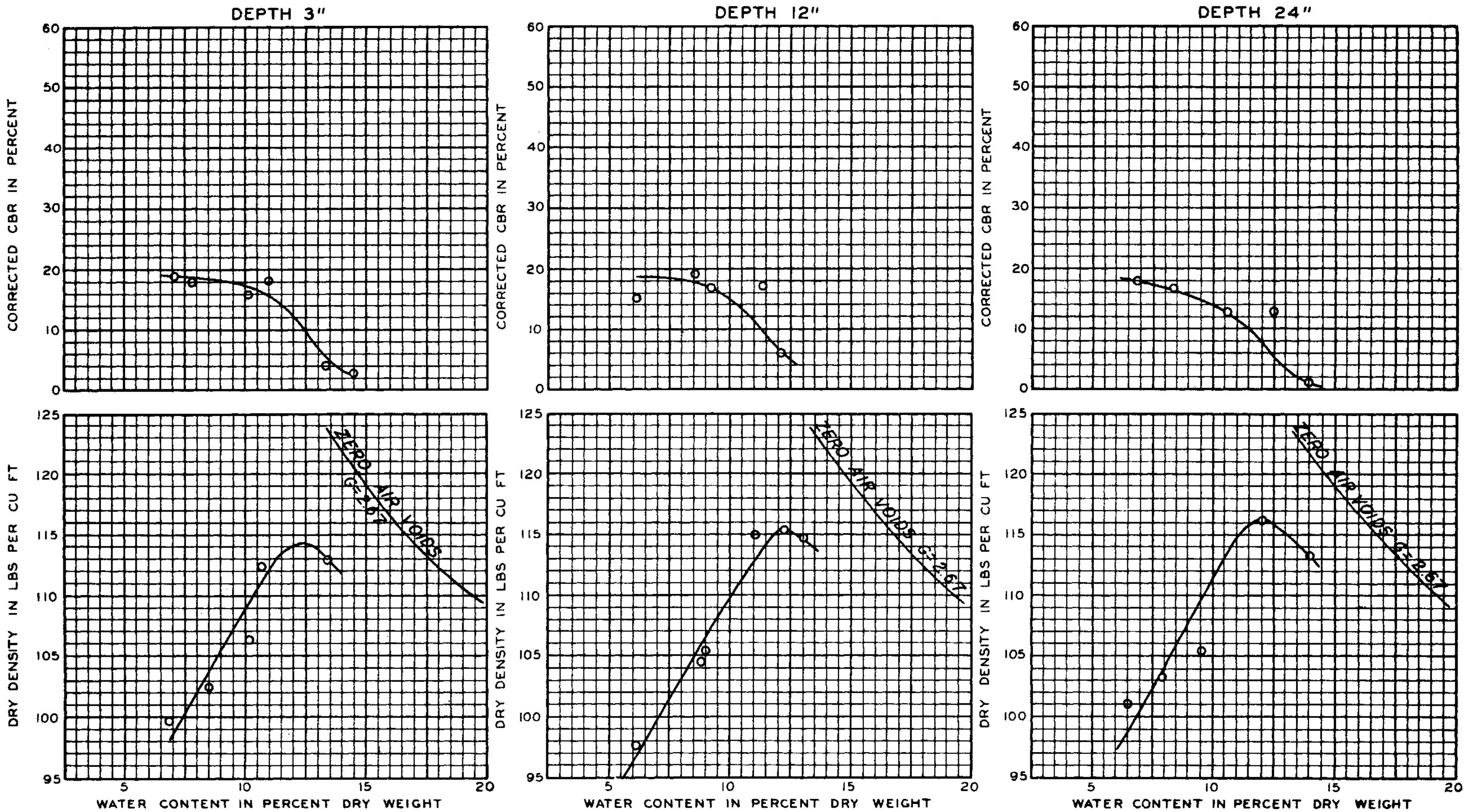
WATER CONTENT AND DENSITY VALUES USED IN WATER CONTENT VS DENSITY PLOTS WERE OBTAINED FROM UNDISTURBED VOLUMETRIC SAMPLES TAKEN IMMEDIATELY ADJACENT TO CBR TEST.

VARIATION OF FIELD IN-PLACE CBR AND DENSITY WITH WATER CONTENT

SECTION 2 - 450-PSI SHEEPSFOOT ROLLER - 9 PASSES

FIGURE 15

FIGURE 16

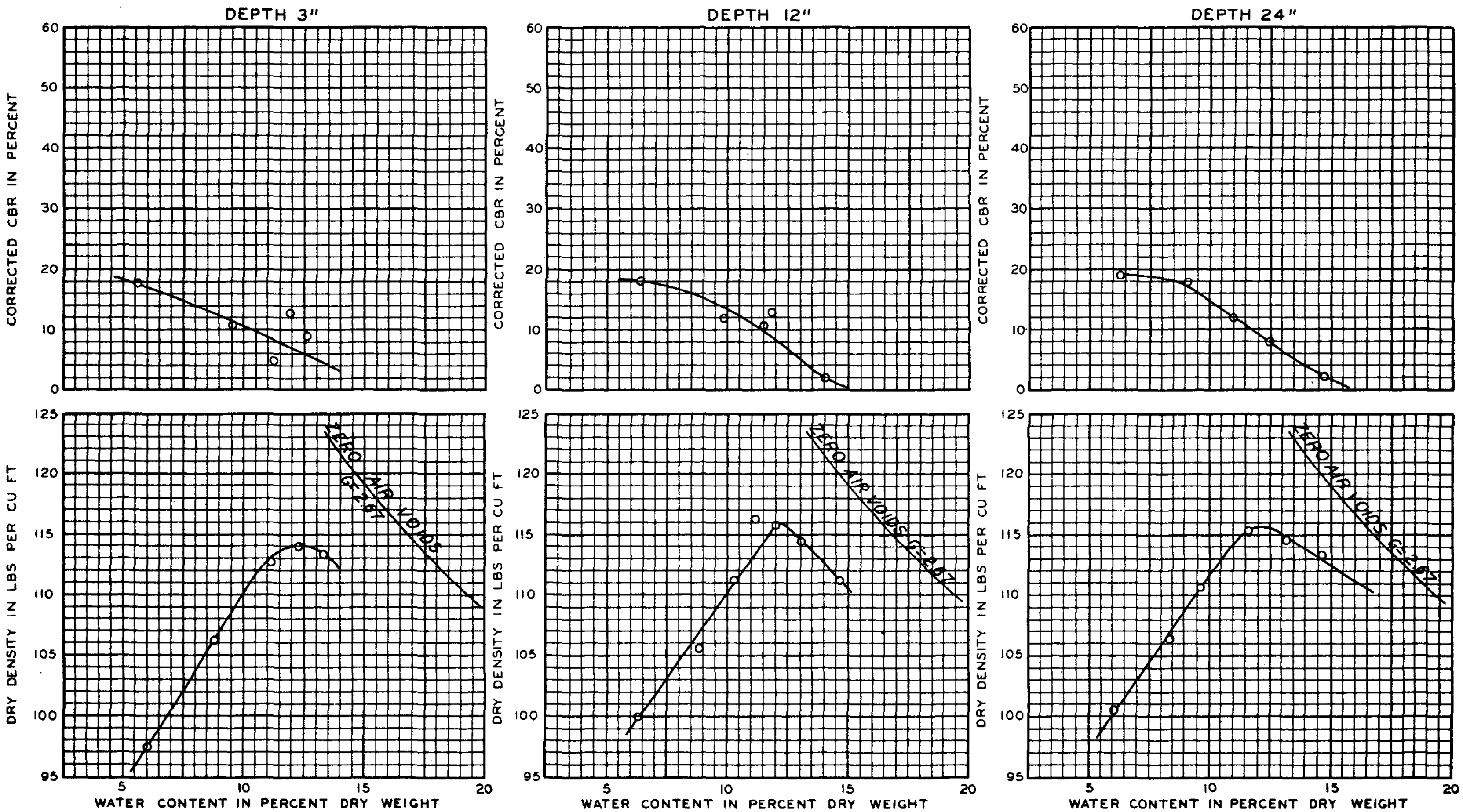


NOTES: WATER CONTENT VALUES USED IN CBR VS WATER CONTENT PLOTS WERE OBTAINED FROM DISTURBED SAMPLES TAKEN IMMEDIATELY BENEATH CBR PENETRATION PISTON.

WATER CONTENT AND DENSITY VALUES USED IN WATER CONTENT VS DENSITY PLOTS WERE OBTAINED FROM UNDISTURBED VOLUMETRIC SAMPLES TAKEN IMMEDIATELY ADJACENT TO CBR TEST.

VARIATION OF FIELD IN-PLACE CBR AND DENSITY WITH WATER CONTENT

SECTION 6 - 1,500-LB WOBBLE-WHEEL LOAD - 6 COVERAGES



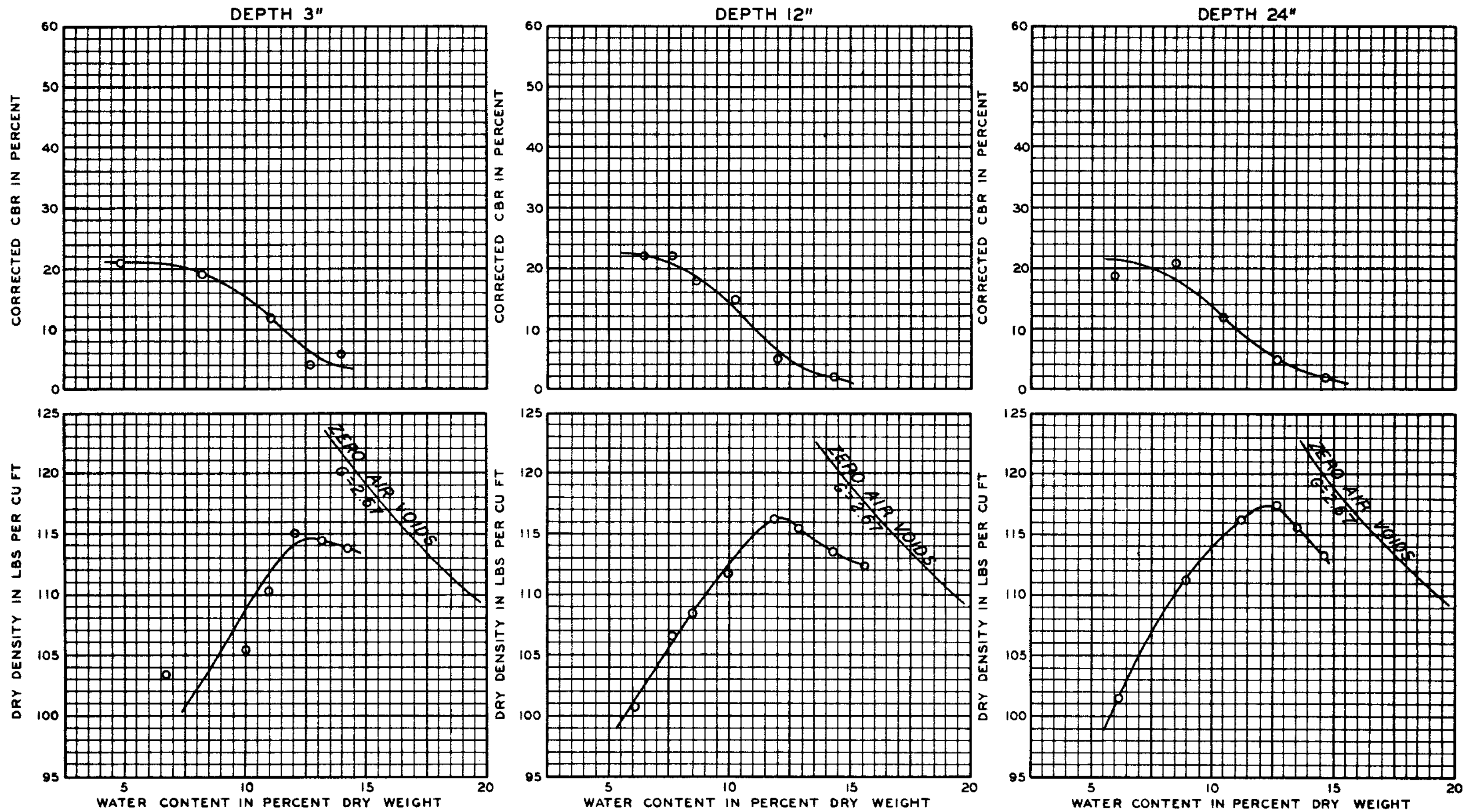
NOTES: WATER CONTENT VALUES USED IN CBR VS WATER CONTENT PLOTS WERE OBTAINED FROM DISTURBED SAMPLES TAKEN IMMEDIATELY BENEATH CBR PENETRATION PISTON.

WATER CONTENT AND DENSITY VALUES USED IN WATER CONTENT VS DENSITY PLOTS WERE OBTAINED FROM UNDISTURBED VOLUMETRIC SAMPLES TAKEN IMMEDIATELY ADJACENT TO CBR TEST.

VARIATION OF FIELD IN-PLACE CBR AND DENSITY WITH WATER CONTENT
SECTION 8-20,000-LB WHEEL LOAD-4 COVERAGES

FIGURE 17

FIGURE 18

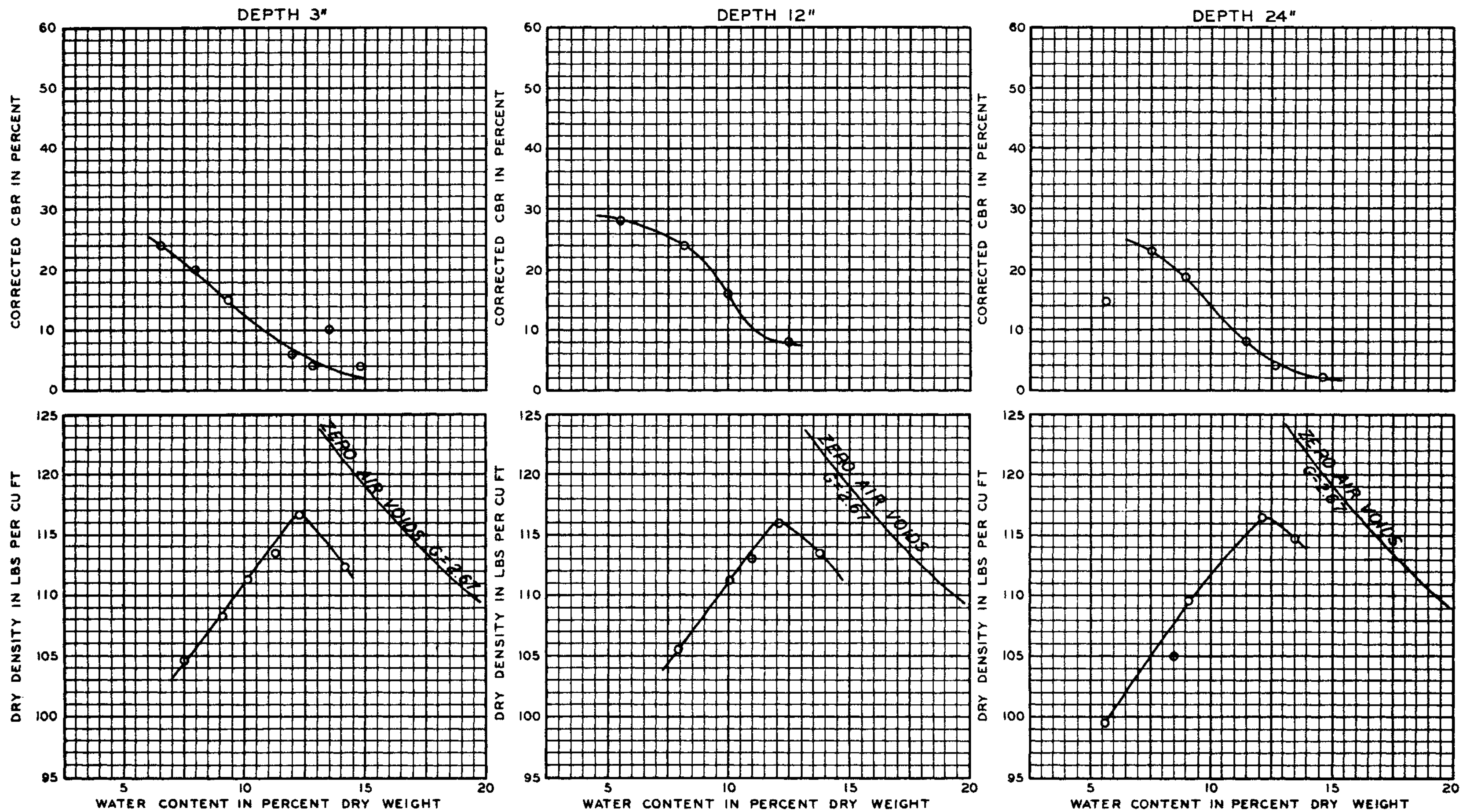


NOTES: WATER CONTENT VALUES USED IN CBR VS WATER CONTENT PLOTS WERE OBTAINED FROM DISTURBED SAMPLES TAKEN IMMEDIATELY BENEATH CBR PENETRATION PISTON.

WATER CONTENT AND DENSITY VALUES USED IN WATER CONTENT VS DENSITY PLOTS WERE OBTAINED FROM UNDISTURBED VOLUMETRIC SAMPLES TAKEN IMMEDIATELY ADJACENT TO CBR TEST.

VARIATION OF FIELD IN-PLACE CBR AND DENSITY WITH WATER CONTENT

SECTION 9-40,000-LB WHEEL LOAD-4 COVERAGES



NOTES: WATER CONTENT VALUES USED IN CBR VS WATER CONTENT PLOTS WERE OBTAINED FROM DISTURBED SAMPLES TAKEN IMMEDIATELY BENEATH CBR PENETRATION PISTON.

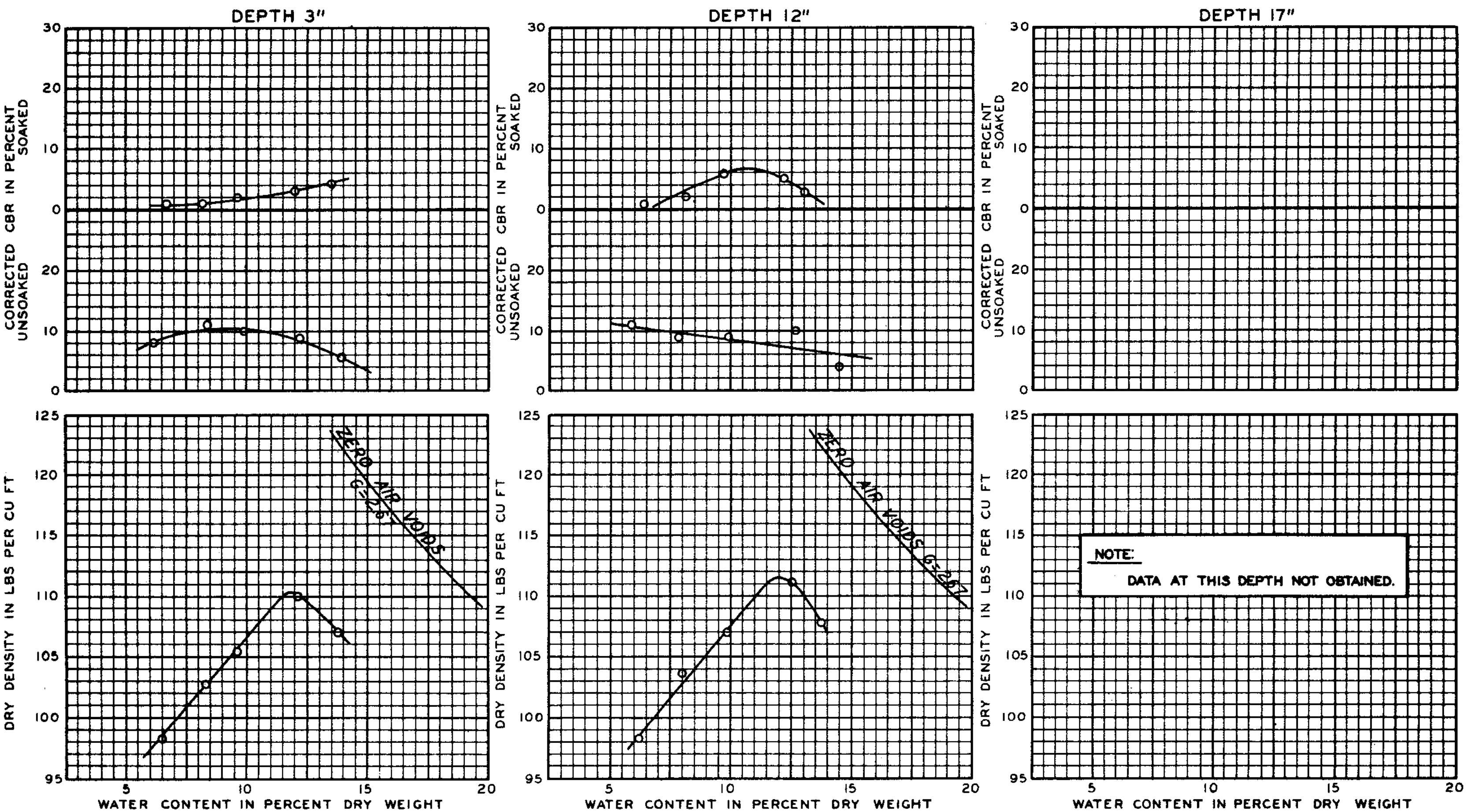
WATER CONTENT AND DENSITY VALUES USED IN WATER CONTENT VS DENSITY PLOTS WERE OBTAINED FROM UNDISTURBED VOLUMETRIC SAMPLES TAKEN IMMEDIATELY ADJACENT TO CBR TEST.

VARIATION OF FIELD IN-PLACE CBR AND DENSITY WITH WATER CONTENT

SECTION 9-40,000-LB WHEEL LOAD-8 COVERAGES

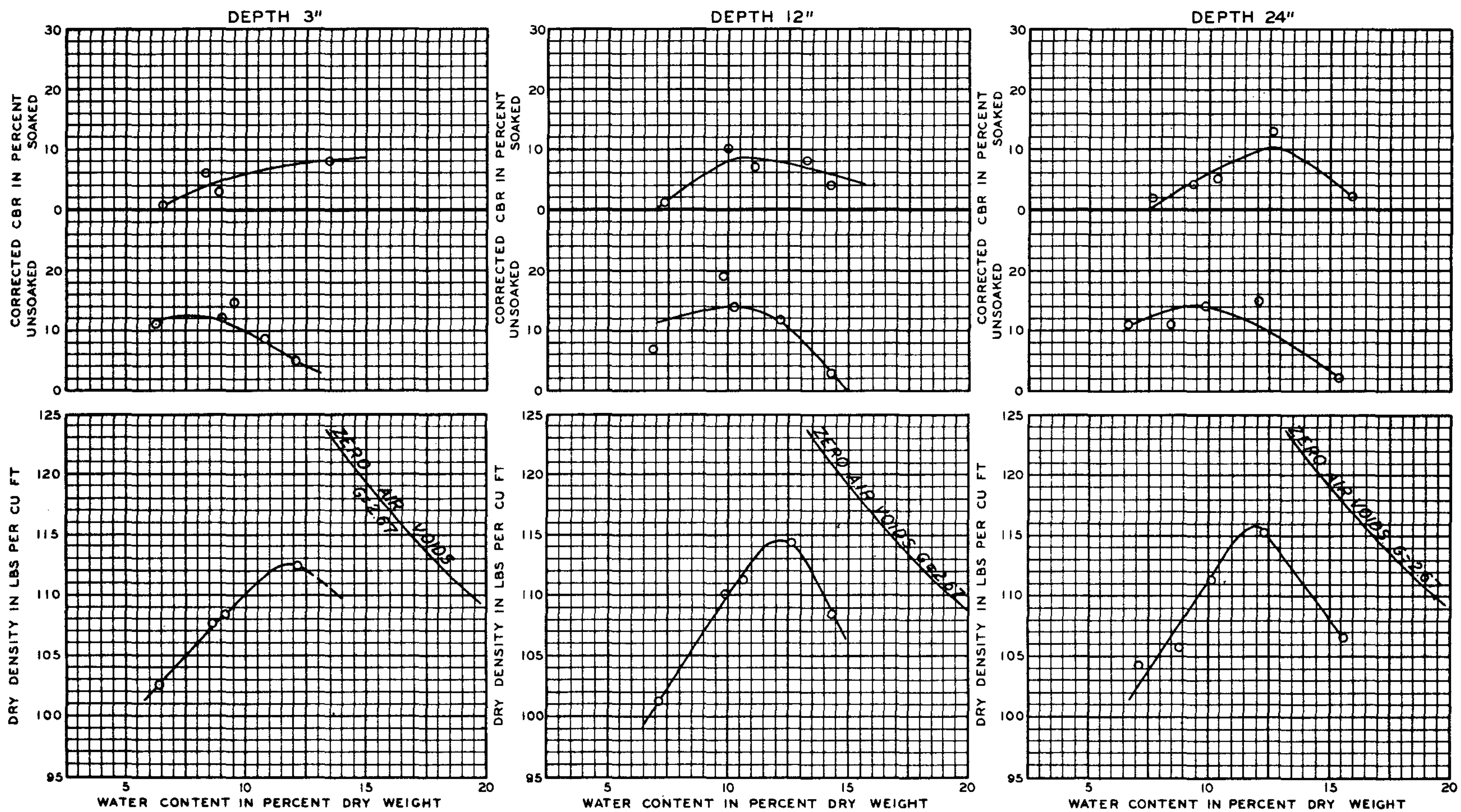
FIGURE 19

FIGURE 20



NOTE: ALL WATER CONTENT, DENSITY AND CBR VALUES SHOWN ABOVE WERE OBTAINED ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS.

VARIATION OF CBR AND DENSITY WITH WATER CONTENT ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS
SECTION 5-34,500-LB TRACTOR-3 COVERAGES



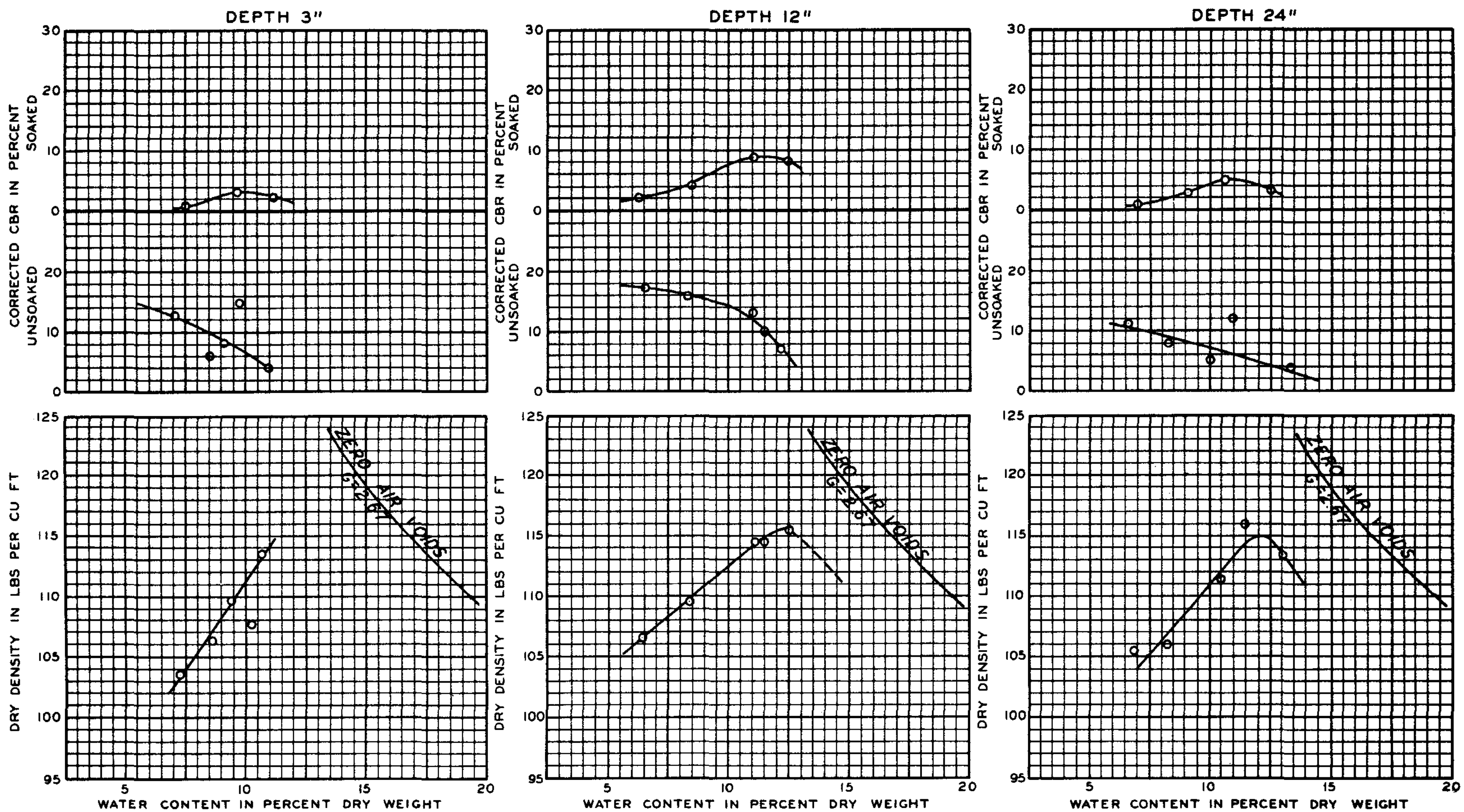
NOTE: ALL WATER CONTENT, DENSITY AND CBR VALUES SHOWN ABOVE WERE OBTAINED ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS.

VARIATION OF CBR AND DENSITY WITH WATER CONTENT ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS

SECTION 3-250-PSI SHEEPSFOOT ROLLER - 9 PASSES

FIGURE 21

FIGURE 22

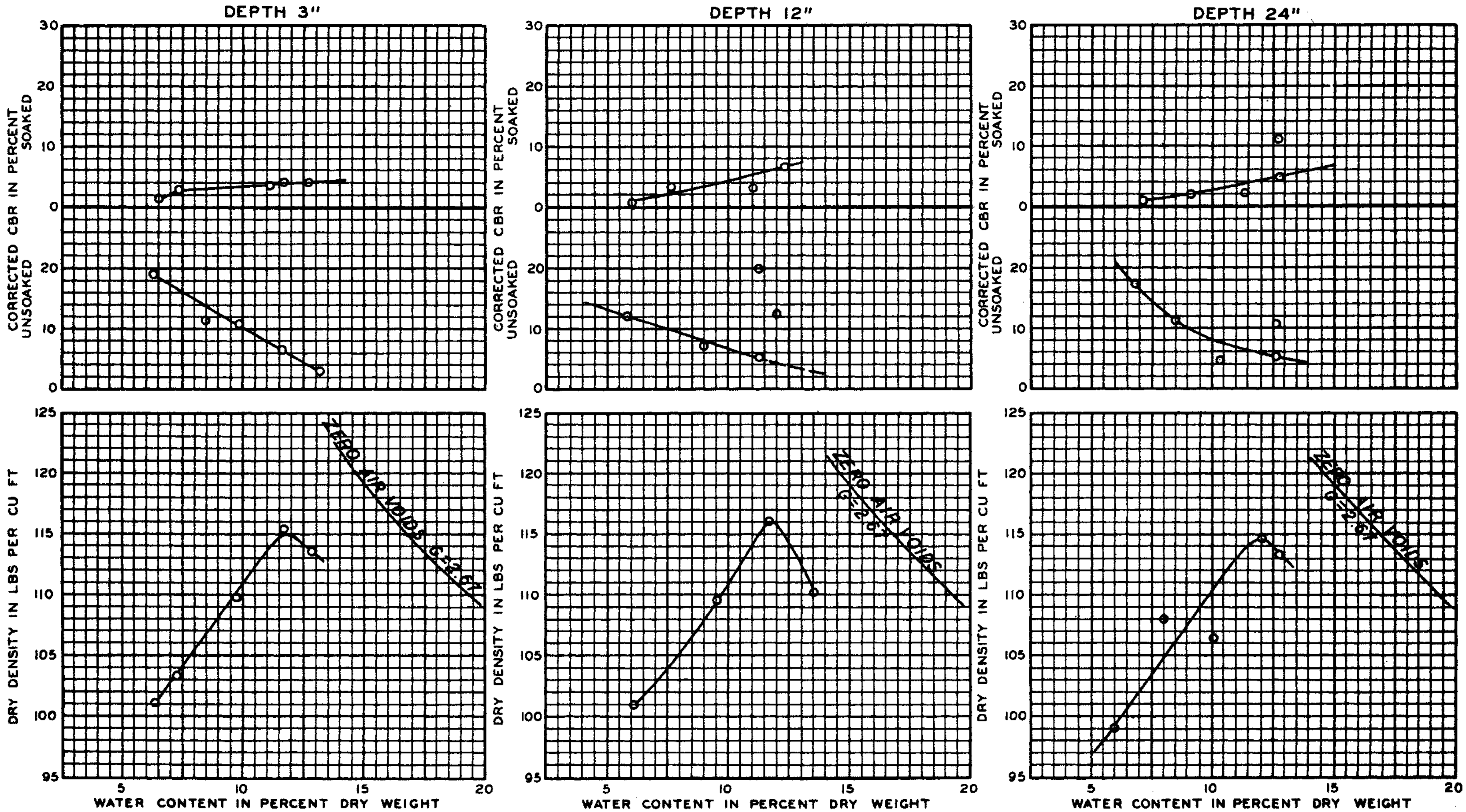


NOTE: ALL WATER CONTENT, DENSITY AND CBR VALUES SHOWN ABOVE WERE OBTAINED ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS.

VARIATION OF CBR AND DENSITY WITH WATER CONTENT ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS

SECTION 2-450-PSI SHEEPSFOOT ROLLER-9 PASSES

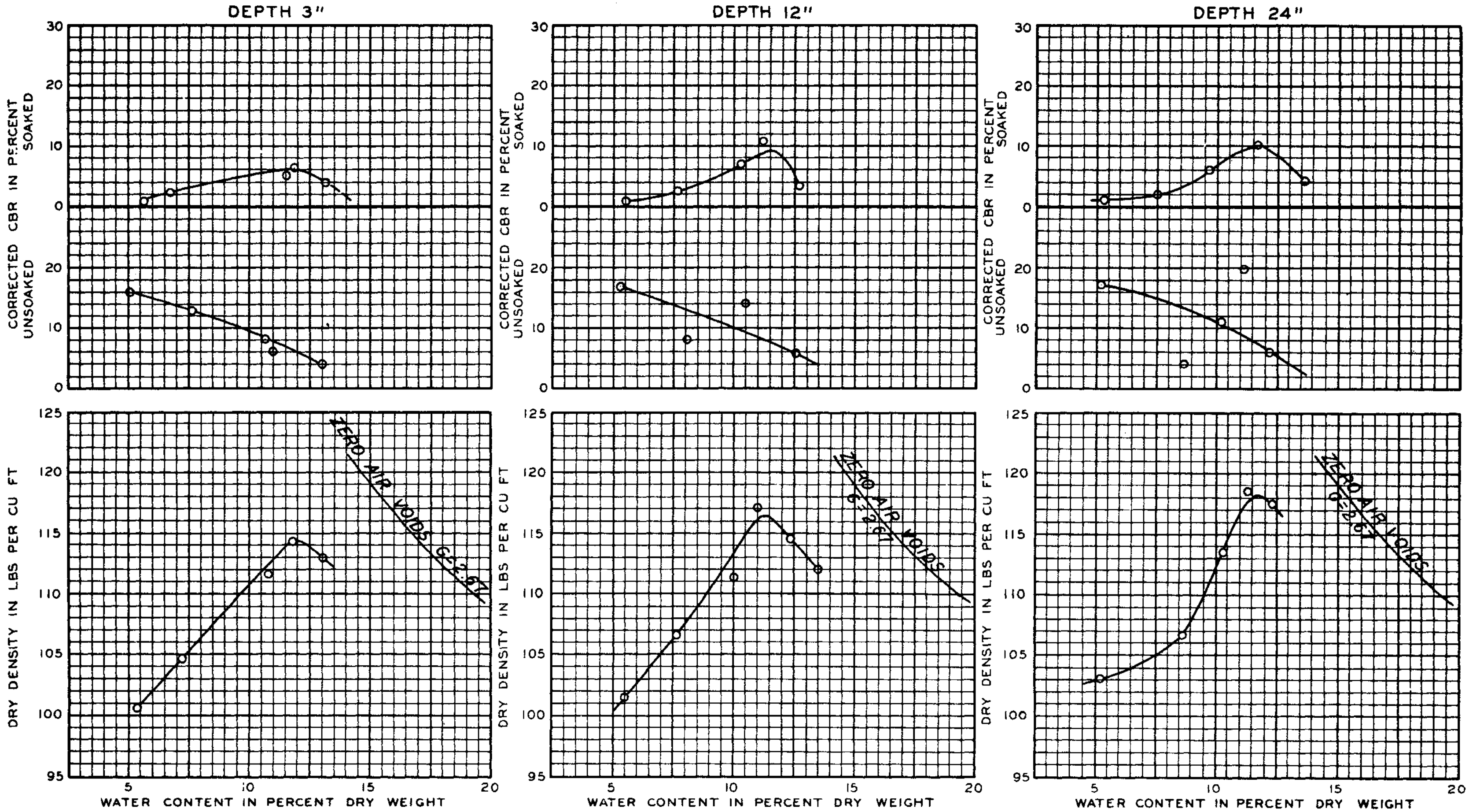
FIGURE 23



NOTE: ALL WATER CONTENT, DENSITY AND CBR VALUES SHOWN ABOVE WERE OBTAINED ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS.

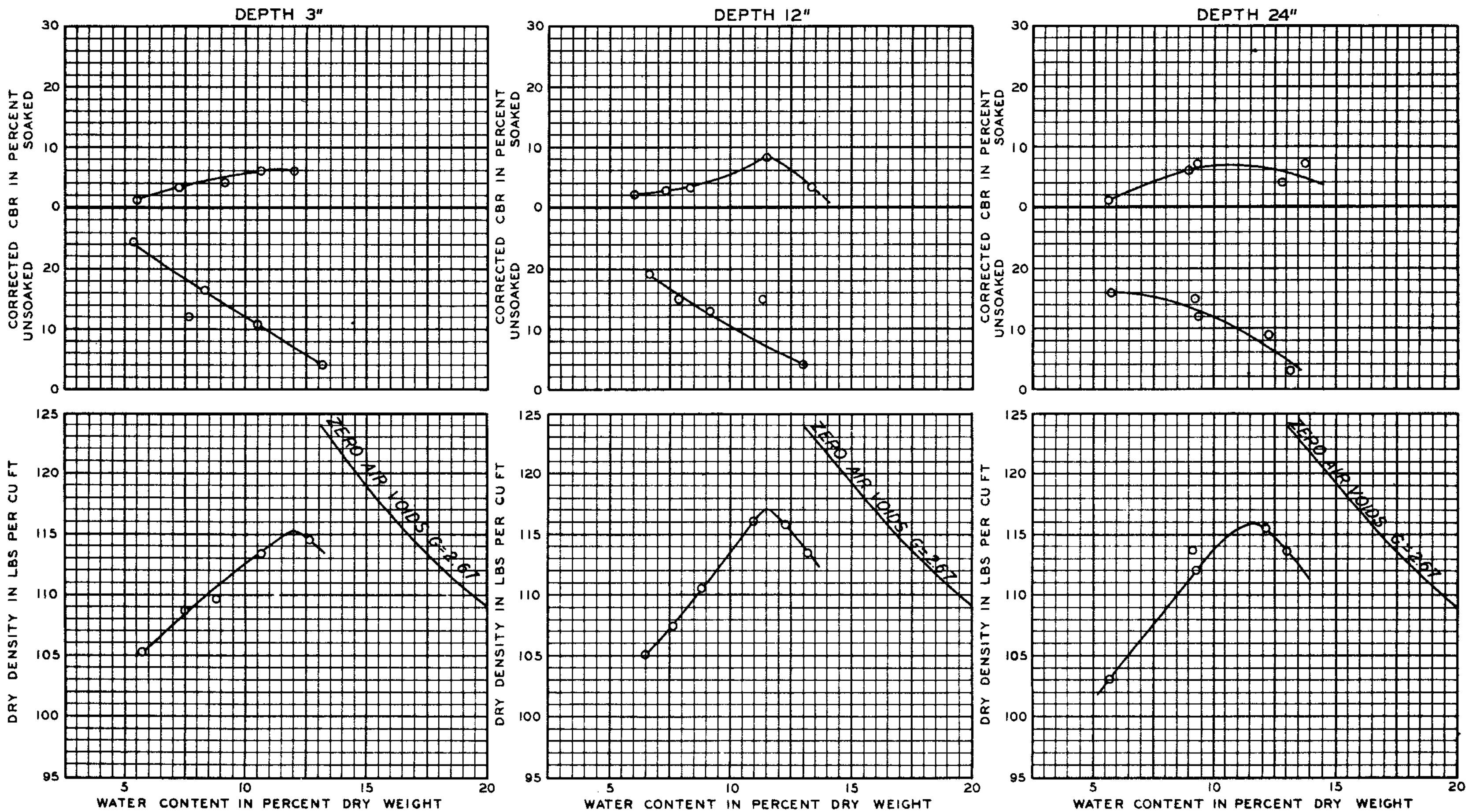
VARIATION OF CBR AND DENSITY WITH WATER CONTENT ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS
SECTION 6-1,500-LB WOBBLE-WHEEL LOAD-6 COVERAGES

FIGURE 24



NOTE: ALL WATER CONTENT, DENSITY AND CBR VALUES SHOWN ABOVE WERE OBTAINED ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS.

VARIATION OF CBR AND DENSITY WITH WATER CONTENT ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS
SECTION 8-20,000-LB WHEEL LOAD-4 COVERAGES

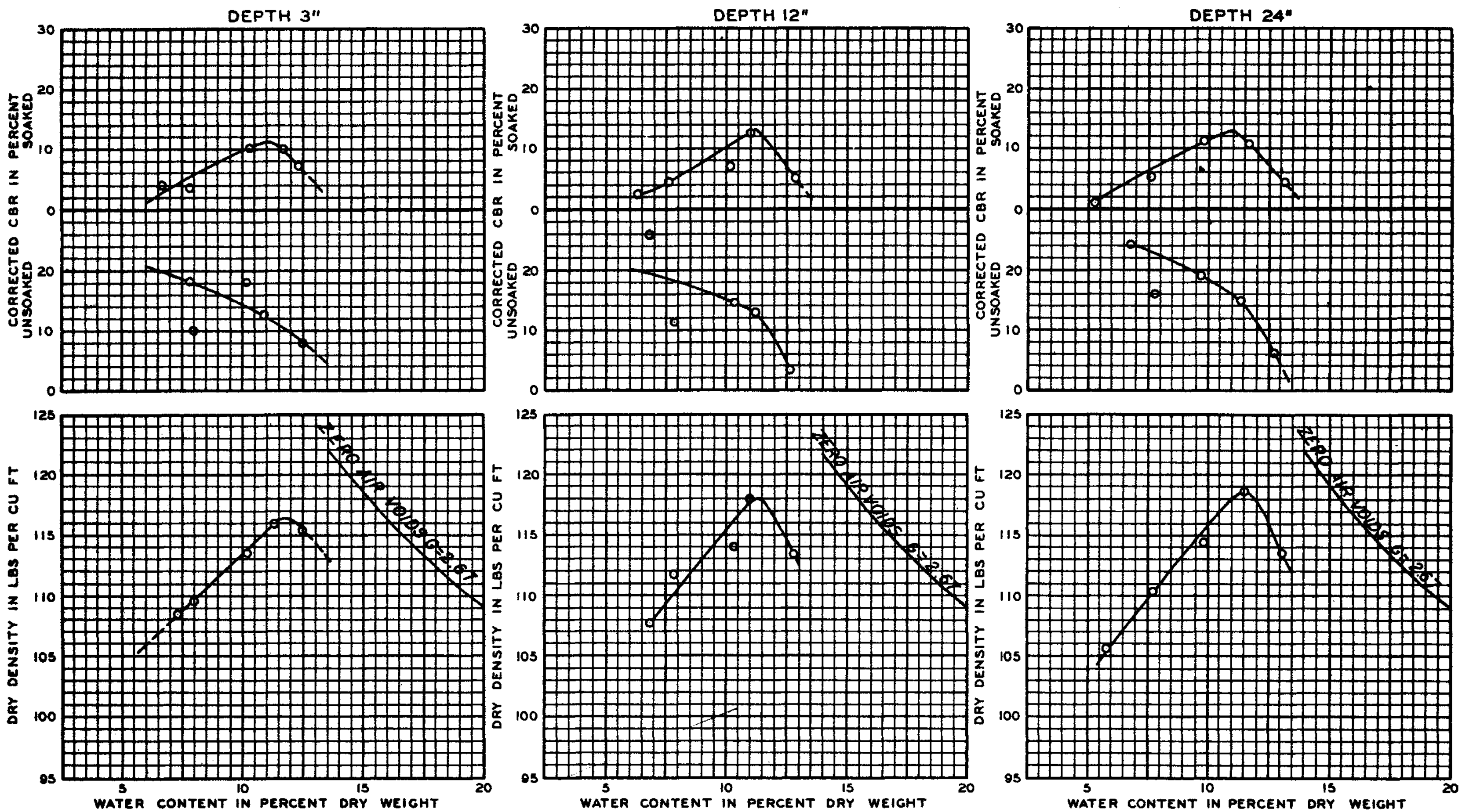


NOTE: ALL WATER CONTENT, DENSITY AND CBR VALUES SHOWN ABOVE WERE OBTAINED ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS.

VARIATION OF CBR AND DENSITY WITH WATER CONTENT ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS
SECTION 9-40,000-LB WHEEL LOAD-4 COVERAGES

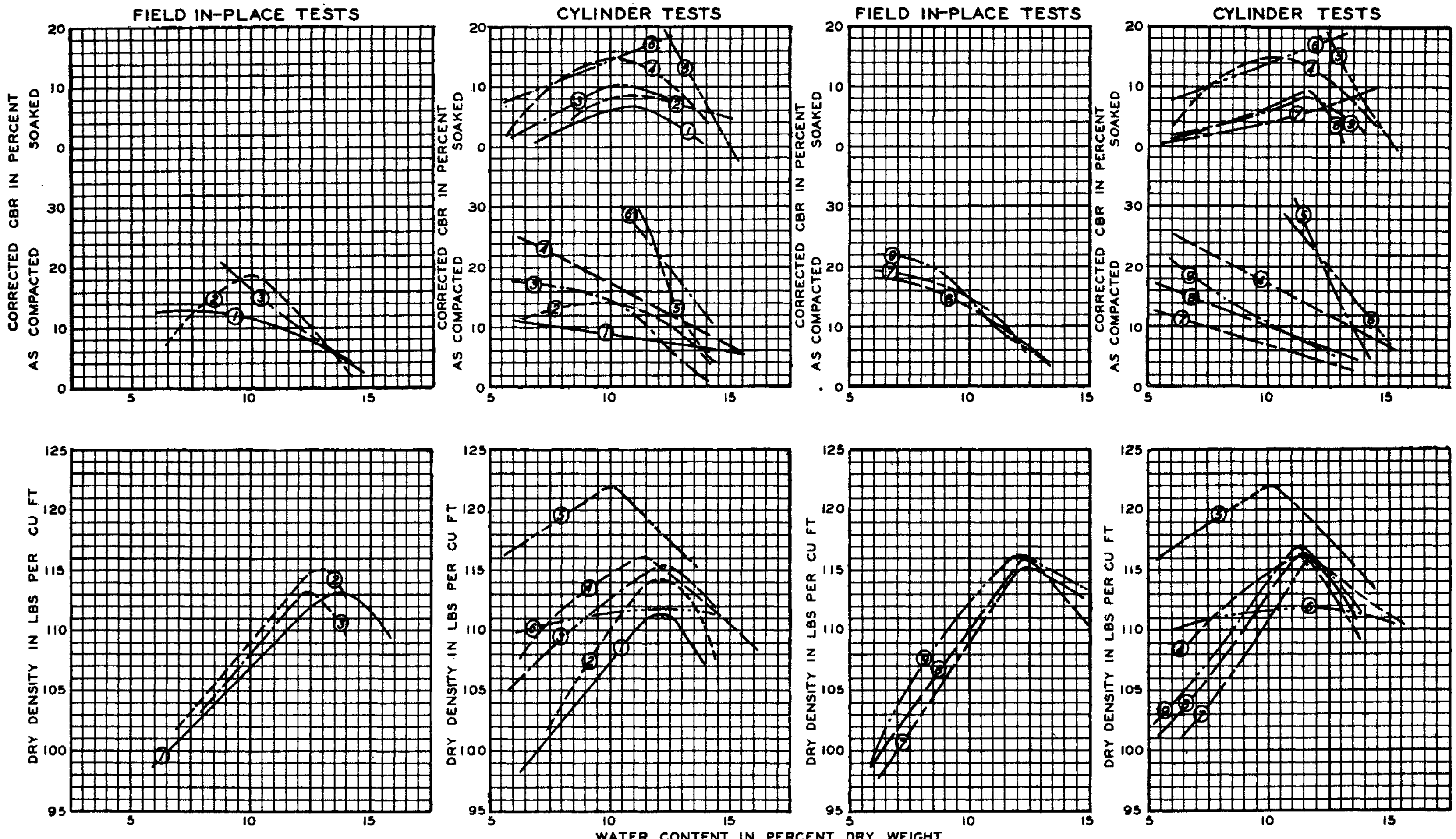
FIGURE 25

FIGURE 26



NOTE: ALL WATER CONTENT, DENSITY AND CBR VALUES SHOWN ABOVE WERE OBTAINED ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS.

VARIATION OF CBR AND DENSITY WITH WATER CONTENT ON UNDISTURBED SAMPLES TAKEN IN CBR MOLDS
SECTION 9-40,000-LB WHEEL LOAD-8 COVERAGES



LEGEND

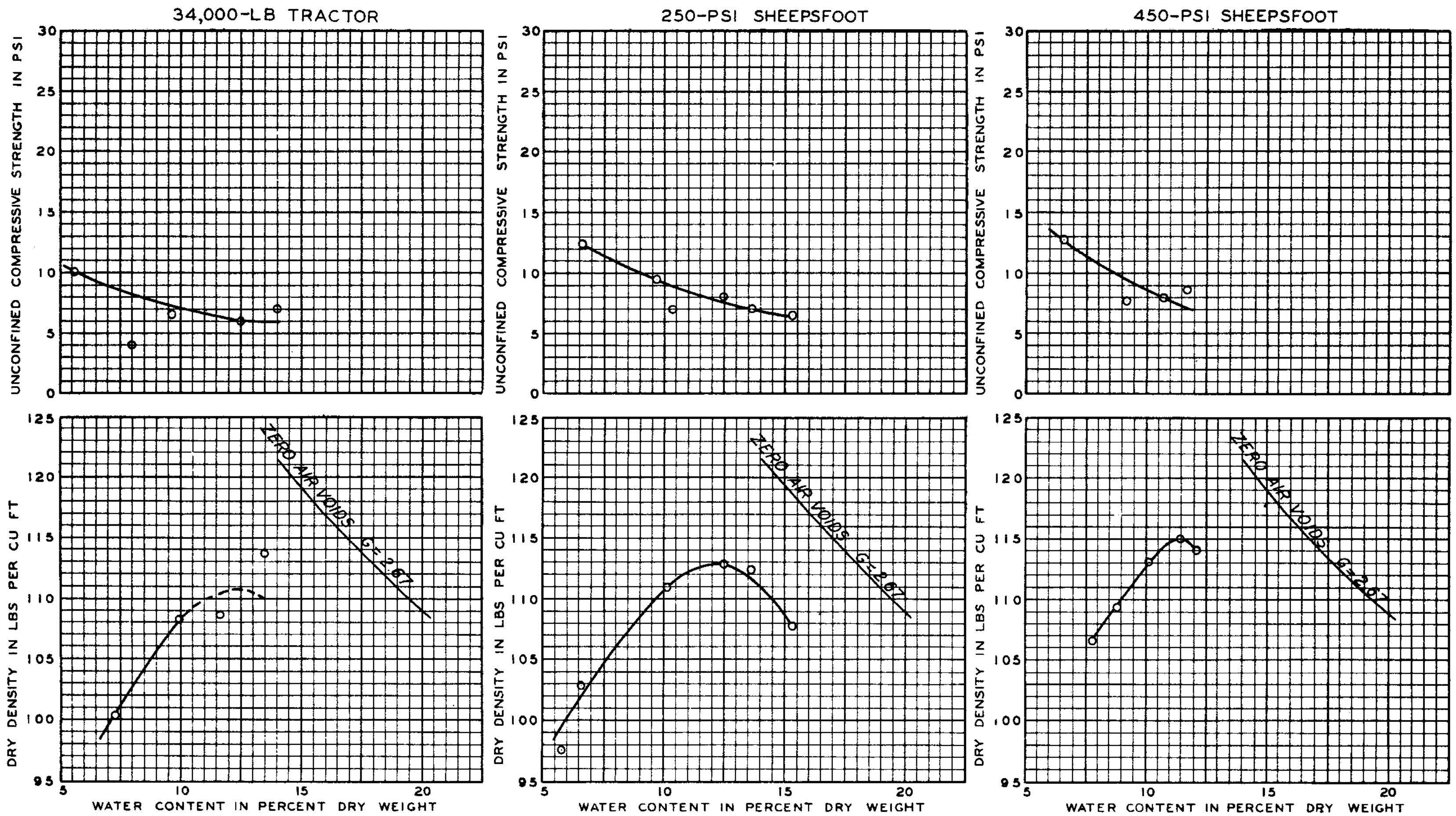
- ① 34,500-LB TRACTOR - 3 COVERAGES
- ② 250-PSI SHEEPSFOOT ROLLER - 9 PASSES
- ③ 450-PSI SHEEPSFOOT ROLLER - 9 PASSES
- ④ STD. AASHO EFFORT
- ⑤ MOD. AASHO EFFORT
- ⑥ 2,000-PSI STATIC PRESSURE
- ⑦ 1,500-LB WOBBLE-WHEEL LOAD - 6 COVERAGES
- ⑧ 20,000-LB WHEEL LOAD - 4 COVERAGES
- ⑨ 40,000-LB WHEEL LOAD - 4 COVERAGES

NOTE: FIELD DATA SHOWN ARE FOR TESTS AND SAMPLES TAKEN 12 INCHES BELOW TOP OF COMPACTED FILLS.

COMPARISON OF FIELD AND LABORATORY COMPACTION AND CBR

FIGURE 27

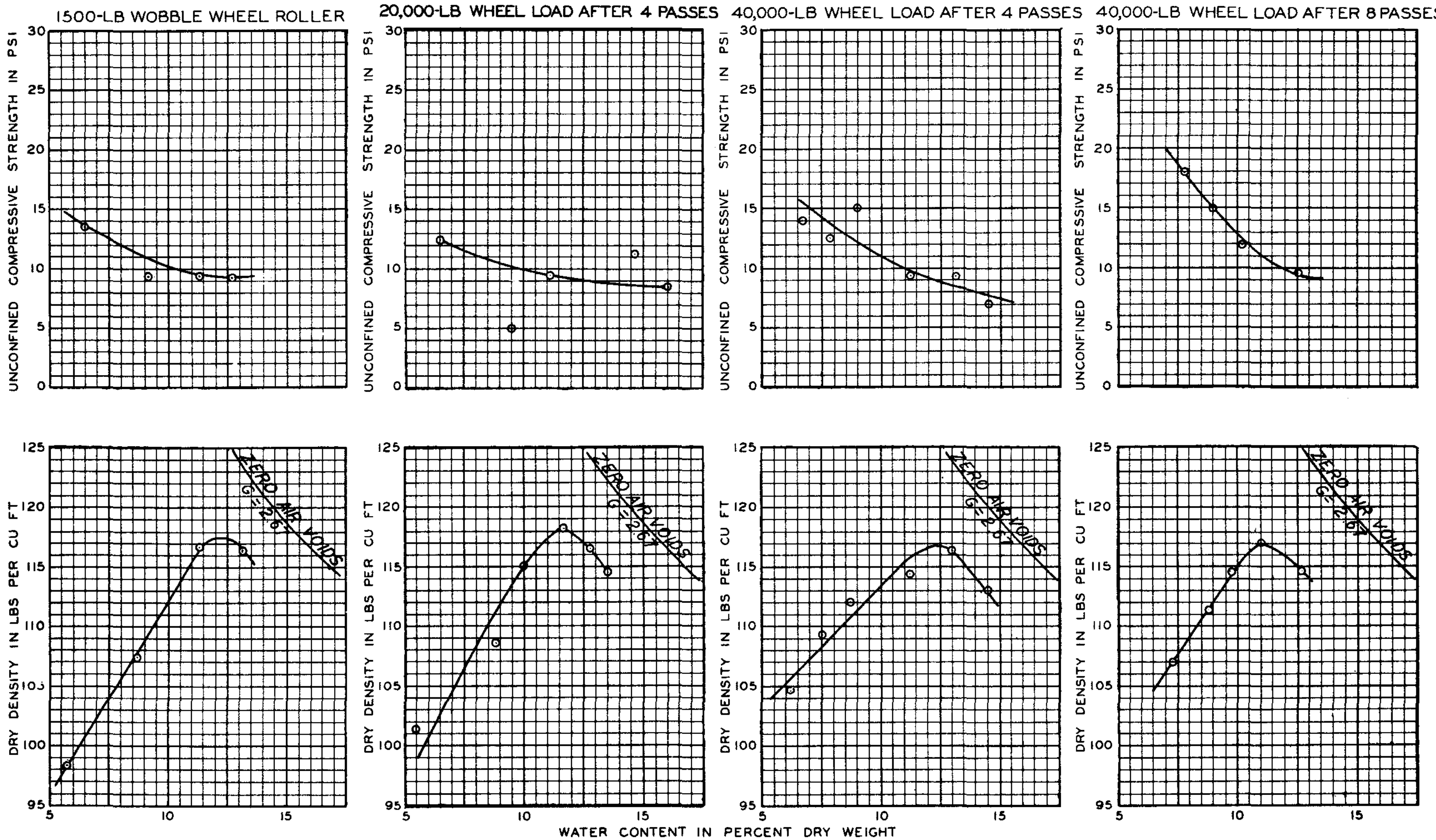
FIGURE 28



NOTES: TESTS PERFORMED ON 2" BY 4" SPECIMENS CUT FROM UNDISTURBED TEST PIT SAMPLES.
ALL SPECIMENS TESTED AT THE IN-PLACE WATER CONTENT AND DENSITY.

VARIATION OF UNCONFINED COMPRESSIVE STRENGTH AND DENSITY WITH WATER CONTENT

UNDISTURBED SAMPLES



NOTES: TEST PERFORMED ON 2" BY 4" SPECIMENS CUT FROM UNDISTURBED TEST PIT SAMPLES.

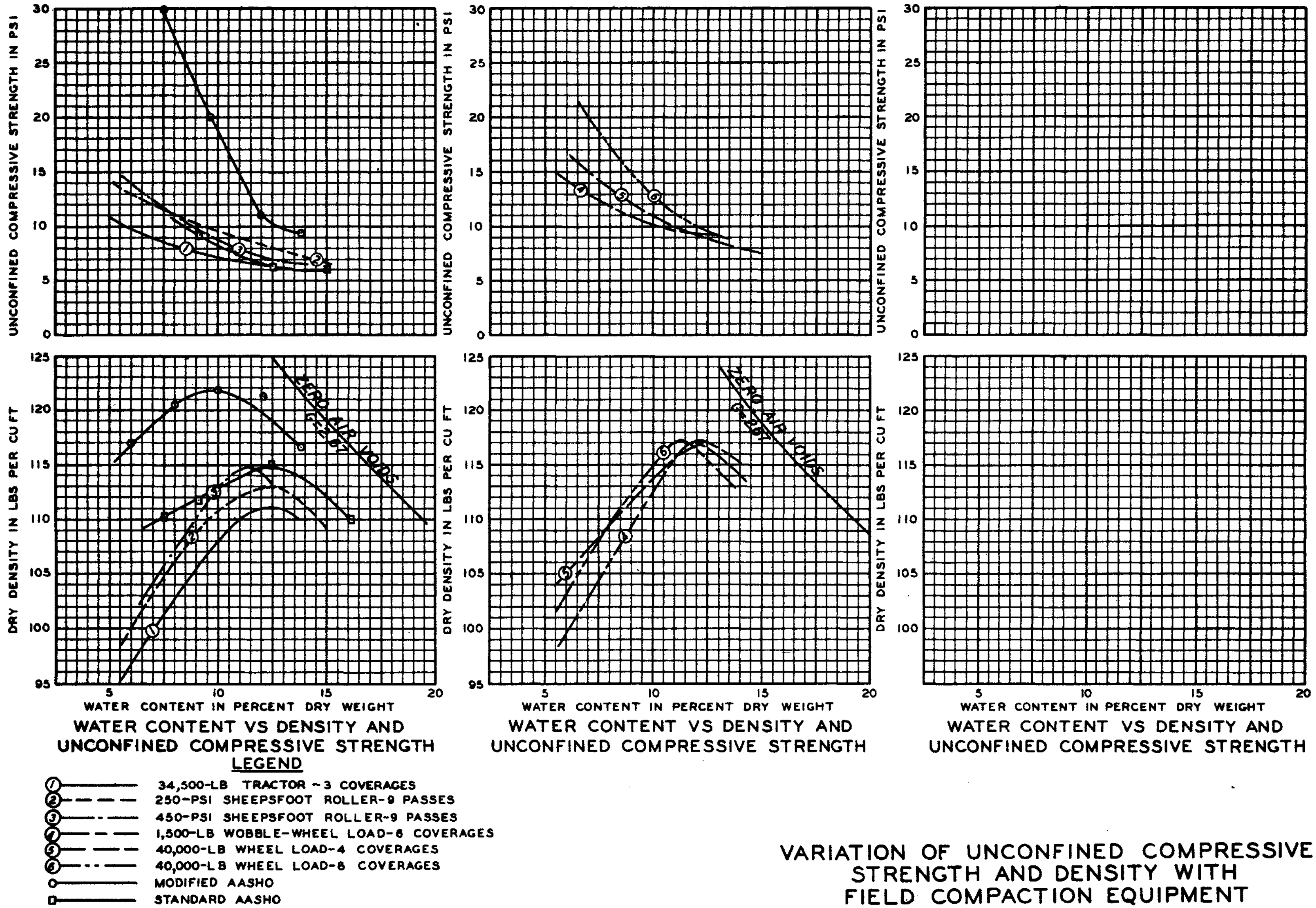
ALL SPECIMENS TESTED AT THE IN-PLACE WATER CONTENT AND DENSITY.

VARIATION OF UNCONFINED COMPRESSIVE STRENGTH AND DENSITY WITH WATER CONTENT

UNDISTURBED SAMPLES

FIGURE 29

FIGURE 30



VARIATION OF UNCONFINED COMPRESSIVE STRENGTH AND DENSITY WITH FIELD COMPACTION EQUIPMENT